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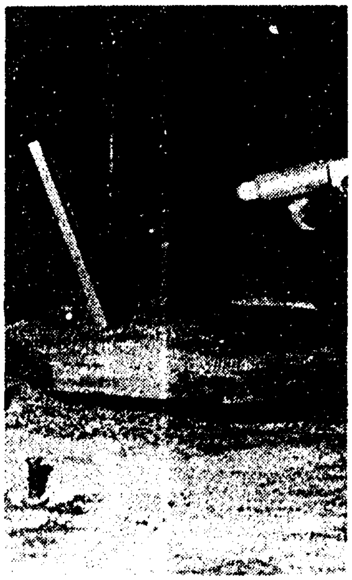

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TECHNICAL REPORT REMR-EM-7

HIGH-SOLIDS AND 100-PERCENT SOLIDS COATINGS: A STATE-OF-THE-ART INVESTIGATION

by

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Problem Area		Problem Area	
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS

TOP - Media blasting a test panel

BOTTOM - Conducting a mandrel bend test.

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The Corps of Engineers has used solution vinyl paints for corrosion protection of hydraulic structures on inland waterways for many years. These coatings have an excellent service life, however liquid paint contains a high amount of solvents. Recently enacted volatile organic compound (VOC) air pollution regulations put severe restrictions on solvents in paints.

The purpose of this research was to investigate generic high-solids and 100-percent solids coatings under laboratory conditions and identify coatings, based on their performance in the laboratory tests, as candidates for field testing. Tests were conducted on 24 coatings to provide data that could be used to write performance specifications for high-solids and 100 percent solids coatings.

The most severe laboratory test was the salt water immersion test. Seven coating systems of varied generic types survived this test and the fresh water immersion test without blistering. Six of them are recommended for field testing. Eleven coating systems performed satisfactorily (did not blister) in the fresh water immersion test and are recommended for field testing. Film thickness was not a significant factor in determining coating performance in the immersion tests nor in the accelerated weathering tests.

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PREFACE

This study was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Electrical and Mechanical problem area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Work Unit 32417, "Development of High-Solids Coatings," for which Mr. Alfred D. Beitelman is principal investigator. Mr. James E. Crews (CFCW-O) was the HQUSACE technical monitor.

Mr. Jesse A. Pfeiffer, Jr., is the REMR Coordinator of the Directorate of Research and Development, HQUSACE; Mr. Crews and Dr. Tony C. Liu serve as the REMR Overview Committee; Mr. William F. McCleese, US Army Engineer Waterways Experiment Station, is the REMR Program Manager; Dr. Ashok Kumar was the Problem Area Leader.

Appreciation is expressed to K.K. Karpoff for the extensive work he performed on this project. This work included panel preparation, testing, data acquisition, and data recording. His help in assembling the report and in many coordinating efforts connected with the project was also of great value.

This laboratory work was conducted by Mr. John Baker, of the Bureau of Reclamation, Denver Office, Research and Laboratory Services Division, for the US Army Construction Engineering Research Laboratory (USACERL). The field testing was performed by Mr. Beitelman of USACERL. The technical editor was Gloria J. Wienke, USACERL Information Management Office.

COL Everett R. Thomas is Commander and Director of USACERL. Dr. L.R. Shaffer is Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
gallons (US liquid)	3.785412	litres
inches	25.4	millimetres
mils	0.0254	millimetres
pounds	453.6	grams

*To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

HIGH-SOLIDS AND 100-PERCENT SOLIDS COATINGS: A STATE-OF-THE-ART INVESTIGATION

PART I: INTRODUCTION

Background

1. The Corps of Engineers has used solution vinyl paints for corrosion protection of hydraulic structures on inland waterways for many years. These coatings have an excellent service life, however liquid paint contains a high amount of solvents. Recently enacted volatile organic compound (VOC) air pollution regulations put severe restrictions on solvents in paints. Specifically, these regulations limit the total amount of organic solvents that may be in liquid paint. Use of low solids paints, such as solution vinyls, would violate these regulations; use of high-solids or 100-percent solids coatings would be in compliance with the regulations. Although these regulations are currently only in effect in specific areas of several states, similar regulations will eventually be enacted on a wider basis. To comply with both the existing and anticipated regulations, it is necessary to evaluate potential coatings to replace those currently used.

Objective

2. The investigation had the following objectives:

a. Investigate generic high-solids and 100-percent solids coatings under laboratory conditions that simulate the exposures the coatings experience in use on hydraulic structures.
b. Identify coatings, based on their performance in the laboratory tests, as candidates for field testing.
c. Obtain data to compare high-solids and 100-percent solids coating systems with some widely used conventional coating systems, such as the VR-6 and V-766 vinyl solution coating systems and the MIL-P-24441, type I, 2-package epoxy-polyamide coating system.
d. Provide data that could be used to write performance specifications for high-solids and 100-percent solids coatings.

Approach

3. A literature search was conducted to identify generic high solids and 100-percent solids coating systems that had demonstrated desirable properties in either laboratory or field evaluations. This survey was used to

identify coatings that would be good candidates for use on hydraulic structures. A telephone survey and a review of manufacturers' data sheets were used to select the specific commercially available coating systems to be tested in the investigation. Two standard high-VOC coatings were included in the investigation for comparison: MIL-P-24441, type I, formulas No. 150, 151, and 152 epoxy-polyamide, and Bureau of Reclamation specification VR-6 vinyl resin. Two low-VOC, waterborne vinyl coating systems were also included. Testing was conducted on 24 coating systems.

4. The coating samples obtained from the manufacturers were applied to solvent-cleaned and media-blasted steel panels. Methods of application were: polyfoam applicators, bristle brushing, conventional spraying, airless spraying, and plural component airless spraying. Both basic coating system properties (pot life, etc.) and applied coating system properties (immersion resistance, etc.) were tested.

PART II: PROCEDURE

Experiment Design

5. The design for laboratory testing of the coatings was as follows:

   a. Duplicate panels of each coating system were placed in the saltwater (SW) immersion, freshwater (FW) immersion, and QUV accelerated weathering tests.

   b. Single, unexposed panels of each coating were subjected to multiple pulls for the pulloff adhesion test.

   c. Single, unexposed panels of each coating were subjected to the mandrel bending (flexibility) test.

   d. Four unexposed panels of each coating were set aside for future testing.

Photographs of the laboratory equipment used in the investigation are in Appendix A, Section 1.

Products Tested

6. Twenty-four coating systems representing the following generic or application variations were tested:

   a. Two elastomeric aromatic polyurethane coating systems differing only in the application technique used for the primer.

   b. Two elastomeric aromatic-aliphatic polyurethane coating systems differing only in the application technique used for the primer.

   c. A nonelastomeric polyurethane coating system.

   d. Eleven variations of epoxy coating systems.

   e. Two hybrid coating systems consisting of an epoxy primer, an aromatic polyurethane intermediate coat, and either an aromatic or aliphatic polyurethane topcoat.

   f. A coal-tar epoxy coating system (coal-tar epoxy is being considered a separate generic type of coating system because it has only limited interchangeability with other generic types of epoxy coating systems).

   g. Two variations of waterborne vinyl coating systems.

   h. A solventborne vinyl resin coating system.

   i. Two variations of a polyester resin coating system.

Detailed information on the individual coating systems tested appears in Tables 1 and 2.

Table 1

Commercially available coatings systems tested

System No.	Components/minimum number of coats [1]()	[2]Generic type	[2]Volume Solids (%)	[1]Target dry-film thickness (mils)	[2,3]VOC Content (g/L)
1	Topcoat (1)	Elastomeric Aromatic Polyurethane (2-pkg)	100	30	-
	Primer (1)	Isocyanate Polyol (2-pkg, applied with peaks of profile covered, but showing)	34	2	645
2	Topcoat (2)	Elastomeric Aromatic-Aliphatic Polyurethane (2-pkg)	70	30	325
	Primer (1)	Isocyanate Polyol (2-pkg, applied with peaks of profile covered, but showing)	34	2	645
3	Self-priming (2)	Epoxy-amine (2-pkg)	80	16	187
4	Self-priming (1)	Nonelastomeric Aromatic Polyurethane (2-pkg)	100	50	-
5	Topcoat (1)	Elastomeric Aromatic Polyurethane (2-pkg, Aromatic Diamine Cured)	52	30	420
	Primer (1)	Epoxy-Polyamide (2-pkg)	43	5-6	513
6	Topcoat (2)	Aliphatic Polyurethane (2-pkg, applied over system No. 5 to create an improved system for exterior exposure)	67	2-3	324
7	Topcoat (2)	Epoxy-Cycloaliphatic Polyamine, Modified (2-pkg)	61	4	311
	Primer (1)	Epoxy-Polyamide (2-pkg)	71	5	325
8	Topcoat (1)	Epoxy-Cycloaliphatic Polyamine, Modified (2-pkg)	61	2	311
	Intermediate Coat (1)	Epoxy-Polyamide (2-pkg)	71	5	325
	Primer (1)	Epoxy-Polyamide Corrosion Inhibiting (2-pkg, contains zinc chromate)	40	2	531
9	Self-Priming (2)	Epoxy-Polyamine (2-pkg, capable of being applied under water)	100	20	-
10	Topcoat (1)	Cycloaliphatic Amine Cured Epoxy (2-pkg)	75	5-7	214
	Primer (1)	Cycloaliphatic Amine Cured Epoxy (2-pkg)	77	4-6	195
11	Self-Priming (2)	Epoxy-Polyamide (2-pkg)	83	16	195
12	Self-Priming (1)	Coal-Tar Epoxy (2-pkg)	100	20	-
13	Self-Priming (2)	Epoxy-Polyamide (2-pkg)	66	12	323

(Continued)

(Sheet 1 of 3)

Table 1 (Continued)

System No.	Components/minimum number of coats [1]()	[2]Generic type	[2]Volume Solids (%)	[1]Target dry-film thickness (mils)	[2,3]VOC Content (g/L)
14	Self-Priming (1)	Water-borne, High-Build Acrylic Modified Vinyl	50	8	205
15	System consisting of a primer, red body coats, gray body coat, seal coats (6)	VR-6 Solvent-borne Vinyl	18.5 (ave.)	10	665
16	Topcoat (1)	Highly Modified Styrene Polyester; 2% MEK peroxide hardener (2-pkg)	100	5-8	-
	Intermediate Coat (2)	Highly Modified Styene Polyester; 2% MEK peroxide hardener (2-pkg)	100	18-22	-
	Primer (1)	Highly Modified Styrene Polyester; 2% MEK peroxide hardener (2-pkg)	100	3-4	-
17	Topcoat (1)	Highly Modified Styrene Polyester; 2% MEK peroxide hardener (2-pkg)	100	5-8	-
	Intermediate Coat (2)	Highly Modified Styrene Polyester; 2% MEK peroxide hardener (2-pkg, this intermediate coat differs in formulation from the system 16 intermediate coat in that it contains a silica type filler)	100	18-20	-
	Primer (1)	Highly Modified Styrene Polyester; 2% MEK peroxide hardener (2-pkg)	100	3-4	-
18	Topcoat (1)	MIL-P-24441, Formula 152, type I, Epoxy-Polyamide (2-pkg)	60	2-3	370
	Intermediate Coat (1)	MIL-P-24441, Formula 151, type I, Epoxy-Polyamide (2-pkg)	60	2-3	370
	Primer (1)	MIL-P-24441, Formula 150, type I, Epoxy-Polyamide (2-pkg)	60	2-3	350
19	Topcoat (1)	Proprietary two coating system based on MIL-P-24441 with higher solids (2-pkg)	65	4-5	340
	Primer (1)	Proprietary two coating system based on MIL-P-24441 with higher solids (2-pkg)	65	4-6	340
20	Topcoat (1)	Bisphenol Epoxy-Aromatic Amine (2-pkg)	100	12	-
	Intermediate Coat (1)	Bisphenol Epoxy-Aromatic Amine (2-pkg, fibrous)	100	40	-
	Primer (1)	Bisphenol Epoxy-Aromatic Amine (2-pkg)	60	3-4	331

(Continued)

(Sheet 2 of 3)

Table 1 (Concluded)

System No.	Components/minimum number of coats [1]()	[2]Generic type	[2]Volume Solids (%)	[1]Target dry-film thickness (mils)	[2,3]VOC Content (g/L)
21	Topcoat (1)	Bisphenol Epoxy-Aromatic Amine (2-pkg)	100	12	-
	Intermediate Coat (1)	Bisphenol Epoxy-Aromatic Amine (2-pkg, fibrous)	100	40	-
	Primer (1)	Bisphenol Epoxy-Aromatic Amine (2-pkg)	60	3-4	331
	Pretreatment (1)	Proprietary	4	thin wipe	1098
22	self-priming (3)	Water-borne Acrylic Modified Vinyl	50	6	205
23	Topcoat (2)	Elastomeric Aromatic Polyurethane (2-pkg)	100	30	-
	Primer	Isocyanate Polyol (2-pkg, applied normally, 2 mils over peaks of profile)	34	2	645
24	Topcoat (2)	Elastomeric Aromatic-Aliphatic Polyurethane (2-pkg)	70	30	325
	Primer (1)	Isocyanate Polyol (2-pkg, applied normally, 2 mils over peaks of profile)	34	2	645

Notes
1. Coatings manufacturers' recommendations
2. Data supplied by coatings manufacturers
3. VOC (Volatile Organic Compound) is being considered as negligible for 100 percent solids coatings. These coatings do, however, have a small (less than 15 g/L) VOC content. g/L = grams per liter

(Sheet 3 of 3)

Table 2

Coating Systems Data

System No.	[1]Total Target DFT (mils)	[2]No. of Coats Min. P	I	T	Method of Application	Min. Recommended Blasting Profile (Immersion)	[7]Nonmetallic Surfaces coating is suitable for	Recoating time @75 °F Min. Max. (hours)	[8]Min. curing time @75 °F (days)	Mixing Ratio Pkg A: Pkg B (volume)	Pot life @75 °F (hours)	[9]Est. Cost per Sq. Ft. ($)
1	[illegible]	1		1	P - Conv. or Airless Spray - 2 mils above valleys T - PC Airless Spray (heated)	2.0[5] N	Concrete, Wood, PVC Sheet, HDPE Sheet	P: 0.5-24 T: 0.1-72	4	P-4:1 T-1:1	P-24 T-1	2.40-2.80
2	30	1		2	P - Conv. or Airless Spray - 2 mils Above valleys T - PC Airless or Airless Spray	2.0 N	Concrete, Wood	P: 0.5-24 T: 2-72	4	P 4:1 T 1:1	P 21 T 1	3.47-3.97
3	16	1(sp)		2	T - PC Airless Spray	0.5-2.0 N	Concrete	T: 3-none	3	T-100:105	T 1.5	2.30-320
4	50	(sp)		1	P - PC Airless Spray (heated)	4.0-6.0 N	Concrete, Wood, Fiberglass, Urethane Foam	T: none-6	3	T-2:1	T 0.1	1.50-350
5	[illegible]	1		1	P - Conv. or Airless Spray T - Airless Spray	2.0-3.0 N	Concrete, Plastic, Foam	P: 4-168 T: 1 none	1	P-1:1 T-3:1	P-10 T 2	2.21
6	17-[illegible]	1	1	2	P - Conv. or Airless Spray I - Airless Spray T - Conv. or Airless Spray	2.0-3.0 N	Concrete, Plastic, Foam	P: 4-168 I: 4 none T: 1 [illegible]	1	P-1:1 I-3:1 T 3:1	P 10 I 3 T [illegible]	11.23
7	[illegible]	1	-	2	P - Conv. or Airless Spray T - Conv. or Airless Spray	1.5-2.0 N	Concrete Masonry	P: 12-72 T: 12-72	1	P 3:1 T 1:1	P 1 T 1	1.45-155
8	[illegible]	1	1	1	P - Conv. or Airless Spray I - Conv. or Airless Spray T - Conv. or Airless Spray	1.5-2.0 N	Concrete, Masonry	P: 12-72 I: 12-72 T: 12-72	4	P-1:1 I 3:1 T 1:1	P 1 I 4 T 1	1.15-1.55
9	20	(sp)		2	T - Special PC Airless Spray	2.0-2.5 N	Concrete	T: 2-24	1	T-3.2:1	T 1	[illegible]
10	[illegible]	1		1	P - Brush, Conv. or Airless spray T - Brush, Conv. or Airless Spray	2.0-3.0 N	Concrete	P: 8-720 T: 6-720	5	P-1:1 T 1:1	P 1 T [illegible]	0.70-0.83
11	16	(sp)		2	T - Conv. or Airless Spray	2.0 N	Concrete, Wood	T: 16-2181	7	T 1:1	T [illegible]	0.430-0.432

(Continued)

(Sheet 1 of 4)

Table 2 (Continued)

System No.	[1]Total Target DFT (mils)	[2]No. of Coats Min. P	I	T	Method of Application	Min. Recommended Blasting Profile (Immersion)	[7]Nonmetallic Surfaces coating is suitable for	Recoating time @75 °F Min.-Max. (hours)	[8]Min. curing time @75 °F (days)	Mixing Ratio Pkg A: Pkg B (volume)	Pot life @75 °F (hours)	[9]Est. Cost per Sq. Ft. ($)
12	20	(sp)		1	T PC Spray (heated)	2.0-2.5 N	Curing agent and coating for concrete and cement mortar	T: 2.5-12	3	T-1:1	T-0.33	0.352-0.354
13	12	(sp)		2	T Conv. or Airless Spray	2.0-4.0 N	Concrete, Wood	T: 8-4368	2	T-1:1	T-3	0.393-0.413
14	8	(sp)		1	T - Conv. Airless or Air Assisted Airless Spray	1.0-3.0 N	Concrete, Foam, Wood, Cement	T: 3-168	7			1.35-1.60
15	10	1	3	2	P - Conv. or Airless Spray I Conv. or Airless Spray T Conv. or Airless Spray	2.0-2.5 N	Masonry	P: 4-none I: 12-none T: 12-none	10	-	-	0.898
16	26-34	1	2	1	P - Brush, Roller, Pressure Pot Conv., or Airless Spray I - Brush, Roller, Pressure Pot Conv. or airless spray T Brush, Roller, Pressure Pot Conv. or Airless Spray (PC Airless Spray may also be used)	2.5-3.0[5]W	Concrete, Wood, Fiberglass	P: 1-None I: 1-None T: 1-24	0.08	P -12- I - - T - -	P 0.25-0.33 I-0.25 0.33 T-0.25 0.33	1.00-7.00
17	26-34	1	2	1	P - Brush, Roller, Pressure Pot Conv. or Airless Spray I Brush, Roller, or Heavy Duty High Pressure Air Assisted Airless Spray T Brush, Roller, Pressure Pot. Conv. or Airless Spray (PC Airless Spray may also be used)	2.5-3.0 W	Concrete, Wood, Fiberglass	P: 1-None I: 1-None T: 1-24	0.08	P -12- I - - T -	P-0.25-0.33 I 0.33 0.42 T 0.25 0.33	1.00-7.00
18	6-9	1	1	1	P Conv. or Airless Spray I Conv. or Airless Spray T Conv. or Airless Spray	2.0 N	Concrete, Fiber glass	P: 4-6 I: 4-6 T: 4-6	7	P-1:1 I-1:1 T 1:1	P-6 I-6 T-6	0.96-0.98
19	8-10	1		1	P Conv. or Airless Spray T Conv. or Airless Spray	2.0 N	Concrete, Aluminum with proper primer, Fiberglass	P: 4-6 T: 4-6	7	P-1:1 T-1:1	P-4 T-4	0.78-0.81

(Continued)

(Sheet 2 of 4)

Table 2 (Continued)

System No.	[1]Total Target DFT (mils)	[2]No. of Coats Min. P	I	T	Method of Application	Min. Recommended Blasting Profile (Immersion)	[7]Nonmetallic Surfaces coating is suitable for	Recoating time @75 °F Min.-Max. (hours)	[8]Min. curing time @75 °F (days)	Mixing Ratio Pkg A: Pkg B (volume)	Pot life @75 °F (hours)	[9]Est. Cost per Sq. Ft. ($)
20	55-56	1	1	1	P - Airless graco 45 Spray I Airless Graco 45 Spray T Airless Graco 45 Spray	2.5 N	Concrete with Proper Primer	P: 4-120 I: 6-48 T: 6-48	2	[10]P-1:3 I-1:433 T 1:4.53	P 0.6 0.8 I 0.6 0.8 T 0.6 0.8	2.98-3.23
21	55-56	[5](Pr) 1	1	1	Pr - Wipe on P Airless Graco 45 Spray I Airless Graco 45 Spray T - Airless Graco 45 Spray	2.5 N	Concrete with proper primer	Pr: 0.1 Same day P: 4-120 I: 6-48 T: 6-48	2	[10]Pr P-1:3 I-1:4.33 T-1:4.53	P 0.6 0.8 I 0.6 0.8 T 0.6 0.8	3.03-3.28
22	6	(sp)		3	T - Conv. or Airless Spray	1.0-3.0 N	Concrete, Foam, Wood, Cement	T: 3-168	7	-		1.40-1.65
23	32	1		1	[3]P - Conv. or Airless Spray - 2 mils Above Peaks T - PC Airless Spray (heated)	2.0 N	Concrete, Wood, PVC Sheet, HDPE Sheet	P: 0.5-24 T: 0.1-72	4	P-4:1 T-1:1	P-24 T-1	2.52-2.92
24	32	1		2	P - Conv. or Airless Spray - 2 Mils Above Peaks	2.0 N	Concrete, Wood	P: 0.5-24 T: 2-72	4	P-4:1 T-1:1	P-24 T-1	3.59-4.09

Notes

1. DFT - Dry Film Thickness. The thicknesses given are the target DFTs which were recommended by the coatings manufacturers. For actual testing DFTs, see Table Nos. 1,3,4,5,6,7

2. The minimum number of coats for the primer (P), intermediate (I), and top (T) coats are those recommended by the manufacturers of the coatings. In no instance were fewer than the recommended number of coats applied to the testing panels.

3. The principal difference between System Nos. 1 and 2, and 23 and 24, is in the method used to prime the panels. System Nos 1 and 2 had all the peaks of the blasting profile covered with primer, but the profile still showed through. Measurement of the film thickness of the primer was from the bottom of the profile to the just covered peaks. System Nos. 23 and 24 had the primer applied in the conventional manner, with its thickness being measured from the tops of the peaks of the blasting profile to the surface of the primer. PC = plural component.

4. (SP) - (Self Priming). The total number of coats in these coating systems appear under the topcoat columns because they are "one coating" systems.

5. N - Near White Blast, SSPC-SP10
W - White Metal Blast, SSPC-SP5

6. A proprietary wash primer pretreatment is wiped on the surface and the primer is applied over the wash primer a very short time later.
Pr - Pretreatment.

7. The general coatings systems tested in this investigation can be used on surfaces other than steel. However, different primers and/or surface preparation methods are often required.

8. The minimum curing times at an ambient temperature of 75 °F are for immersion service in water, either salt or fresh. They are the minimum curing times required after the final coat has been applied. The manufacturers' advice and instructions must be followed for lower or higher temperatures, or if there are chemical contituents in the water other than those normally present in saltwater or freshwater.

9. The estimated costs per square foot which are given were obtained from the manufacturers of the coatings systems. They include the costs of the coatings used, based on 100 gallon lots of each, and approximate application costs, but are exclusive of surface preparation. These costs pertain to the complete systems and are, of necessity, merely approximations based on average surfaces. They are presented for information only, and, outside of a total context, are not significant. Individual applications will require individual cost estimates/appraisals.

10. Mixing ratio is by weight instead of volume, and is given for general information only. This material is supplied in premeasured units which form "kits" designed to produce a given amount of coating after mixing (between 1 quart and 5 gallons depending on the "kit"). Package A is the hardener component and package B is the resin component.

11. This information was not available from the supplier at the time this report was written.

12. At an ambient temperature of 75 °F these coatings are cured by the addition of 1.25-1.50 percent of MEK peroxide hardener by weight or volume of the resin. For other temperatures, the manufacturer should be consulted as to the proper amounts of MEK peroxide to be added. Accelerators are available for temperatures under 68 °F and extending to below 0 °F. The types and amounts of the accelerators to be added before the MEK peroxide is added may be obtained from the manufacturer. These accelerators were added to the coatings which were tested in the investigation.

Panel Preparation

7. All test samples were prepared on panels cut from sheets of 24- to 38-mil cold-rolled steel, Rockwell "B" hardness of 55 to 65, flat polished to 15 to 25 microinches in roughness, ASTM A 109, A 366 specifications. Immersion panels were 3 by 6 in. with a 1/4-in. hole centered along one 3-in. edge, 1/4-in. from the edge. Panels used for QUV accelerated weathering tests were 2-5/8 by 6 in. and had no hole. All panels were aged for a minimum of 14 days in a controlled temperature and humidity (73 $\pm$2° F and 50 $\pm$2 percent) before testing.

8. All test panels media-blasted in-house were prepared by using a Uni-Blaster, a totally enclosed blasting cabinet manufactured by Inland Manufacturing Company. The blasting media was Humble Abrasive Flint, grade No. 3, produced by Humble Sand, Inc. All test panels were media-blasted on both sides to the profiles approved or suggested by the manufacturers. The panels of all but five of the coating systems were media-blasted and coated in-house using conventional spray, bristle brushes, or polyfoam applicators. Coating systems No. 5, 6, 14, 18, 19, and 22 were coated using airless spraying equipment (not available in-house) in the manufacturers' laboratories or shops on panels supplied and blasted by the in-house laboratory staff. Coating application was carried out with a laboratory staff observer present. System No. 4, which required a deeper profile than could readily be obtained using the media blasting cabinet, was media-blasted with a commercial blasting unit using a heavy, coarse grade of copper slag and applied with plural-component spraying equipment. Both operations were done in a shop by a representative of the coating manufacturer; the special equipment required for these operations was not available in-house. Once again, laboratory staff observers were present. Panels transported to another site for coating application were stored in a carrying case/desiccator. If more than a few hours travel time were involved, the panels were wrapped in anticorrosive paper. Panels to be coated in-house were primed immediately after the media blasting process had been completed. Completed panels were marked on the backs using a white VR-6 vinyl coating to denote the coating system numbers, number of the panel within a given coating system number, and the side number of the panel (either 1 or 2).

9. Efforts were made to achieve the "target" or recommended dry film thicknesses of the coatings. Both wet and dry film thickness measurements were used to monitor the thicknesses of the coatings. In no instance were fewer than the recommended minimum number of coats applied, although additional coats were applied as necessary to assure that the minimum dry film thickness for a given coating system would be achieved. Final total dry film thickness was measured with a PosiTector 2000 using the average of five readings taken at approximately the same location on all panels. The reading

locations formed the corners of a box with a dot at the center. If a reading was in the immersion area of a panel, it was not permitted to be far below average without the panel being rejected. The "testing sides" of the four immersion panels for the immersion tests of an individual coating system were chosen on the basis of proximity to both the target total dry film thickness and to one another. If necessary, a "high" and a "low" panel were paired in each test. The same criteria were used to choose the "testing sides" of the test panels for the QUV accelerated weathering test. The dry film thicknesses of the "back sides" as well as the "testing sides" of the panels were recorded. The remaining panels were put aside for use in testing adhesion and flexibility, or for potential future testing. All panels selected for the immersion and QUV accelerated weathering tests were edge-sealed and marked SW or FW. The number of the duplicate panels, 1 or 2, was also marked. Initial color readings were taken on all of the panels selected for immersion or QUV testing following the minimum aging period in the constant temperature and humidity room.

Pot Life

10. Pot life for the 2-package coating systems was checked during the application phases of panel preparation. The coating materials being applied to the test panels were observed from the time of mixing to the approximate time the materials became stringy and unusable. This time was checked against the manufacturers' data for pot life, adjusted for the temperature of application.

Recoating Time

11. Recoating time was checked as a part of the application phase of panel preparation. Manufacturers' suggested recoating intervals were closely adhered to, and recoating properties and curing times were monitored. All times were extrapolated to the times required at the temperatures of application using the manufacturers' data as a base. The panels were examined visually for any signs of lifting, delamination, etc., at the time of recoating and again before any additional coats were applied.

Curing Time

12. Curing time was also checked as a part of the application phase of panel preparation. The coatings were examined visually and manually. When the coatings were examined manually, suitable solvents were used to clean off contaminants before any further coating application was permitted.

Immersion Testing

13. Both SW and FW immersion testing were based on ASTM D 870. Both immersion tanks had internal dimensions of 36 by 18 by 9-1/2 in. Both had magnetically operated "flapper" plates to circulate the heated water away from the heating elements and to equalize the temperature of the water throughout the tanks. Each tank was aerated with two aquarium-style air pumps and diffusers. Both were operated at a temperature of 100 ±2° F. Both the FW (deionized) and SW tanks were emptied and cleaned after 1500 hours of operation and after the last sets of panels had experienced 3000 hours of exposure.

14. The SW used in the test conformed to ASTM D 1141. Formula A for substitute ocean water was used. To prevent disposal problems, heavy metals were not added. The "sea-salt" in formula A was purchased and mixed with deionized water according to the supplier's instructions. The "sea-salt" solution was adjusted to pH 8.2 using a 0.1N solution of sodium hydroxide. Deionized water with no additives was used in the FW immersion test.

15. Although ASTM D 870 describes the testing of scribed coatings on ferrous substrates as being impractical because of contamination from corrosion products, the panels were scribed with an "X" on the bottom half of the "test" side so the effects of immersion could be observed on the stressed (scribed) "test" sides as well as on the unstressed (continuous film) back sides of the panels. After the tanks were filled to the reference mark, the suspended test panels were immersed approximately three-quarters of their length. Since normal evaporation lowered the level of the water between fillings, there was a transition area on the panels that was sometimes wet and sometimes dry.

16. The test panels were examined weekly. The test panels exposed to SW were rinsed with deionized water before they were examined. All of the test panels were examined visually for rust along the scribe, blistering, etc. Records of the elapsed hours of immersion were carefully maintained. The total elapsed time recorder on the QUV accelerated weathering tester was used as a check. All elapsed times which were recorded are the elapsed times as of the dates the panels were checked, not the precise times at which the events (blistering, etc.) took place.

17. The basic immersion period was 3000 hours for both SW and FW. Test panels that had not blistered by the end of the immersion period will be continued in the immersion tests until blistering occurs. At the end of the 3000-hour immersion period, the test panels were photographed; measured for color; and if they had blisters (immersion failure), checked for adhesion after a minimum of 14 days in the controlled temperature and humidity room. Any panels that exhibited blistering on the scribed or "test" sides were checked for blistering on the unscribed or back sides also. Unblistered test

panels were not checked for adhesion (a destructive test), but kept in the controlled temperature and humidity room until they were reimmersed 1 week later.

QUV Accelerated Weathering Testing

18. The tests were conducted in accordance with ASTM D 4587. QUV accelerated weathering testing was conducted with a QUV unit manufactured by Q-Panel Company. UVB-313 ultraviolet lamps were used. A 4-hour condensation and 8-hour ultraviolet exposure cycle was used. The unit was operated continuously, except for lamp replacement and weekly examination periods. Operating temperatures were 60 to 65° C for the ultraviolet cycles and 40 to 45° C for the condensation cycles. Lamp rotation and replacement were conducted at intervals between 400 and 450 hours. Duplicate test panels were exposed for each coating system. All test panels were scribed with an "X" on the bottom half of the "test" side and were visually inspected for chalking or other defects once a week. When the exposed panels of a coating system had completed the 3000-hour accelerated weathering test, they were tested for degree of chalking, photographed, and measured for color. All elapsed times which were recorded were the elapsed times as of the dates the panels were checked, not the precise times at which the events (first evidence of chalking, etc.) took place.

Elcometer Adhesion Testing

19. ASTM D 4541 was conducted using an Elcometer adhesion tester with a range of 0 to 1000 lb/sq in. An annular bearing ring was used to keep the resultant force normal to the surface. A circular hole cutter (dolly cutter) was used to score through to the substrate around the loading fixtures. The dollies were adhered to the coating surfaces using the prescribed surface preparation method and Ren-Weld RP106/H953 epoxy adhesive, which cures in 24 hours. The epoxy was applied with a volumetric dispenser. Pressure perpendicular to the surface was applied to the dollies for a minimum of 24 hours during the curing time of the epoxy. The adhesion tester was connected to a dolly on a panel under test shortly after the 24-hour cure had been completed. All panels were tested at approximately the same elapsed time after the dollies were adhered to the coatings. The tests were carried out at ambient laboratory temperatures. Control panels were given triplicate (three dollies) testing. The immersion panels removed from testing were given duplicate testing (two dollies each) on the back (unscribed) sides of the panels in the immersion areas. Space limitations did not permit the three dollies to be attached without interfering with the testing procedures. The QUV panels were tested (two dollies each) on the front (scribed side) of the panels above the

scribed area. The degree of adhesive versus cohesive failure, as well as the pulloff value, was noted.

20. To determine the influence of test panel thickness on these results, a supplemental investigation was launched with the cooperation of the manufacturer of System 4. The manufacturer's laboratory supplied 1/8-in.-thick (125 mils versus the 24 to 38 mils standard) steel panels that had been blasted and coated with System 4. When the Elcometer pulloff adhesion test was carried out on the 125-mil panels, consistent values of 1000+ lb/sq in. were obtained, versus an average of 403 lb/sq in. for the control panel of the investigation. To further evaluate if the variation was due to the difference in test panel thickness, the manufacturer's laboratory prepared and coated standard (24- to 38-mil) test panels supplied by the investigating laboratory. Three "pulls" were made on each of two of these panels. With the exception of one "outlier" at 1000+ lb/sq in., the values (in lb/sq in.) obtained were: 300, 300, 425, 400, and 300. These results show that test panel thickness is a distinct and important variable in the test and must be stated as one of the conditions under which the test was conducted.

Mandrel Bend Testing

21. ASTM D 1737 the mandrel bend test, was run on a spare coated immersion-type panel for each coating system. A Gardner mandrel set was used to run the tests. Each coating system was bent around a 1-in. mandrel. The nature of any failure that occurred was noted.

Color Measurement

22. ASTM D 2244 was used to compute color difference data in CIE 1976 CIELAB (L*, a*, b*) color space. The L*, a*, b* Color System was selected because of its ability to simply and graphically describe the nature and direction of color shifts between two panels. It can also be used to describe the magnitude of the total color shift between the panels. Briefly, the L*, a*, b* color mapping system consists of L* (lightness), +a (red), -a (green), +b (yellow) and -b (blue). Consequently, an increase in L* indicates a lightening of the color, an increase in the +a direction indicates a reddening of the color, and an increase in the +b direction indicates a yellowing of the color, etc. Total color difference is measured by Δ E*ab, which is defined as:

$$[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Illuminant C was used to take the color readings for the immersion tests, and both Illuminant C and Illuminant D65 were used to take the color readings for the QUV accelerated weathering tests. Graphs describing the system appear in

Appendix A, Section 2. Color measurements were made with a Minolta CR-200b Chroma Meter. Readings on the immersion panels were taken before immersion and after 3000 hours of immersion on the test sides of the panels within the scribes and below the intersections of the scribes. After exposure, the test areas were wiped with a tissue to remove loose contaminants. Readings on the QUV panels were taken on the test sides of the panels on the upper half above the scribes. They were taken before exposure and after 3000 hours of exposure.

Chalking Test

23. Chalking was evaluated according to ASTM D 659. A black cloth was used to test most of the coating systems. However, in a few instances, it was necessary to use a white cloth because the chalky material was dark colored. Pictorial Standards of Coatings Defects (Federation of Societies for Coatings Technology, 1979) was used as the source of the visual chalking reference standards.

Blistering Test

24. ASTM D 714 and the visual standards in Pictorial Standards of Coatings Defects were used to evaluate blistering. Blistering on the extreme edges of panels was discounted. Blisters were rated on both size and frequency. If blistering occurred only in certain limited areas, this fact was noted.

PART III: RESULTS

Pot Life

25. All of the two-component (or two-package) coating systems were within the manufacturers' designated times for pot life when they were adjusted for the temperatures of application. However, the optimum application conditions for the various coatings were reached before the end of their pot life periods. This suggests that the stated pot life for a two-component coating, when adjusted for temperature at the time of application, should not be pushed to its upper limit.

Recoating Time

26. Recoating problems were not experienced when the manufacturers' recoating times were followed. Recoating problems were defined as loss of intercoat adhesion, crazing, or wrinkling, that could be detected without destructive testing. A possible recoating problem was experienced with Coating System 22 in the immersion tests. Dense, small blisters appeared early in the immersion tests. These blisters were examined visually and their appearance indicated intercoat rather than substrate blistering; an intercoat adhesion problem.

Curing Time

27. Curing times of all of the coating systems were within the manufacturers' stated limits when adjusted for temperature. The systems were checked visually and manually without marring any testing portions of the test panels.

Immersion Testing

28. Blistering on the scribed or "testing" sides of the immersion test panels was the criteria for their removal from the test following the basic 3000-hour immersion period. The backs of these test panels were coated with the same materials as the scribed sides. Consequently, the panel backs were checked for blistering at the time the immersion tests were terminated. On the scribed sides of the test panels, seven coating systems and one duplicate panel of an eighth coating system exhibited no blistering in either SW and FW immersion during the basic 3000-hour immersion period. These systems will be continued in both SW and FW immersion tests. The eighth coating system, No. 7, will be continued in the FW immersion test, only. Twelve systems survived the basic 3000-hour immersion period in FW only. These coating systems will

be continued in the FW immersion test only. Ten of these systems had no blistering on the backs of the SW immersion test panels at the time of removal. One coating system had blistering on the back of only one panel in the SW immersion test; another coating system had blistering on the backs of both panels in the SW immersion test and on the back of only one panel in the FW immersion test.

29. Observations of the time to 100-percent rusting in the scribe lines were made, but the significance is not definitively established. Certain recorded times did follow a pattern, however. For example, the seven coating systems that survived the basic 3000-hour immersion period in SW without blistering lasted from 822 to 2659 hours before the 100-percent rusting level was reached. The remaining coating systems lasted from 160 to 2327 hours. The respective overall averages for the two groups of panels were 1687 and 779 hours. Another more definite pattern was the shorter number of hours required for the panels immersed in FW to acquire 100-percent rust in the scribe lines. Despite a few reversals, the pattern indicated more rapid rusting in FW.

30. Average dry film thickness was not a determinant of resistance to blistering in either the SW or FW immersion tests. Among the seven coating systems in which both test panels emerged from the basic 3000-hour immersion period in SW without blistering, three systems had an average dry film thicknesses of 50 mils plus, and one system had an average dry film thickness of 13.5 mils. Three systems had average dry film thicknesses of 20.7, 26.7, and 26.9 mils. Two of the thinnest panels in average dry film thickness (8.9 and 9.2 mils) successfully completed the basic 3000-hour immersion period in FW without blistering.

31. Several generic types of coatings were represented in the group of coatings that survived the basic 3000-hour immersion period in SW without blistering, and almost all generic types were represented in the large group of coatings that survived the same immersion period in FW without blistering. The SW immersion group included a 100-percent solids aromatic polyurethane, a high-solids epoxy cycloaliphatic polyamine, a 100-percent solids cycloaliphatic amine cured epoxy, 100-percent solids highly modified styrene polyesters, and a coating system composed of high and 100-percent solids bisphenol epoxy-aromatic amines. The FW group included, in addition to the types already mentioned, an aromatic elastomeric polyurethane, aliphatic polyurethanes (mixtures or topcoats), epoxy-polyamides, a 100-percent solids coal-tar epoxy, and a low-solids solvent-borne vinyl.

32. Color, before and after immersion, was measured at the bottom of the scribed portion of the panels. After immersion, the testing areas were wiped with a tissue before the readings were taken. This was to remove all loose soiling materials. Consequently, the color change data contain several components. Among them are possible leaching, staining, and soil retention. Staining and soil retention appear to be, by far, the major factors involved

in the color changes. All readings were taken at the completion of the basic 3000-hour immersion periods. The Δ E*ab range was 2.21 to 35.13 for the SW immersion test and 2.35 to 36.17 for the FW immersion test. The greater the color difference, the higher the value of ΔE*ab. There seems to be no particular trend for the total color difference readings. Some reversals were noted between SW immersion and FW immersion results and close total color difference readings were noted for both SW and FW immersion results. This is interesting in light of the fact that the SW bath was full of contamination large enough to be seen, whereas the FW bath appeared to be relatively "clean." As the photographs in Appendix A reveal, however, there was more widespread staining as a result of immersion in SW. Most panels became darker, yellower, and greener as a result of both FW and SW immersion. Rust staining from the scribe lines played a role in the color shifts.

33. Detailed results of the SW and FW immersion tests appear in Tables 3, 4, and 5. Photographs of the test panels appear in Appendix A, Section 3.*

QUV Accelerated Weathering Testing

34. QUV accelerated weathering testing was conducted to determine the behavior above the waterline of the coating systems reported on in the section on immersion testing. Chalking and color difference were checked to determine ultraviolet exposure and aesthetic behavior. Chalk ratings ranged from 4 to 10. A rating of 10 is no chalking, and a rating of 2 is very heavy chalking. Colorimeter readings were taken before and after exposure using Illuminant C for one set of readings and Illuminant D65 for a duplicate set of readings for comparison. Illuminant C simulates an overcast day and Illuminant D65 simulates bright daylight. Illuminant D65 has the lower color temperature and gives readings that are "cooler" than those of Illuminant C. The Δ E*ab values for Illuminant C ranged from 2.65 to 29.34 and for Illuminant D65 from 2.08 to 27.00. Detailed chalking, color, and color difference data for the QUV accelerated weathering test are recorded in Table 6. Photographs of the exposed test panels appear in Appendix A, Section 4.

Elcometer Adhesion Testing

35. Values for the control panels in the Elcometer pulloff adhesion test ranged from 95 lb/sq in. to 800 lb/sq in. The range of values for the SW immersion test was 132 lb/sq in. to 658 lb/sq in. and for the FW immersion test was 138 lb/sq in. to 207 lb/sq in. For the QUV accelerated weathering

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*Photographs are presented in black and white. A limited number of color photographs are available to researchers by writing to CECER-EMC, ATTN: Al Beitelman, P.O. Box 9005, Champaign, IL 61826-9005, or by calling (217) 373-7237.

test was 138 lb/sq in. to 207 lb/sq in. For the QUV accelerated weathering test, the range of values was 65 lb/sq in. to 625 lb/sq in. Table 7 contains both the numerical values of all of the pulloff adhesion tests and the description of the general planes of failure (glue line, substrate, etc.). The term NVT (not valid test) appears fairly frequently in the table. In most cases, the test was ruled invalid because of premature damage or failure as a result of the cutting process around the dolly.

Mandrel Bend Testing

36. Mandrel bend testing data (using a 1-in. mandrel) are presented in Table 8. Results obtained from the mandrel bend test are descriptive, not numeric. Photographs of the test panels after they were subjected to mandrel bend testing appear in Appendix A, Section 5.

Table 3

Immersion Test Data - Blistering and Rusting

System No.-Panel No.	Saltwater immersion: Average Dry-film thickness (mils)	[3] Initial blistering (hours)	[3] 100% rusting in scribe lines (hours)	Total hours completed	[1] Blister size and frequency (completion)	Fresh (deionized)water immersion: Average dry-film thickness (mils)	[3] Initial blistering (hours)	[3] 100% rusting in scribe lines (hours)	Total hours completed	[1] Blister size and frequency (completion)
1-1	32.0	1001	665	3148	No. 2 - med. dense No. 4 - med. dense	33.0	-	1001	5745	-
1-2	33.4	1001	665	3148	No. 4 - medium	32.0	-	1996	5745	-
Average or comments:	32.7	1001	665	3148	[2] N.B.O.B.	32.5	-	1499	5745	-
2-1	30.5	664	828	3108	No. 2 - few No. 4 - medium	30.0	-	828	3906	-
2-2	31.3	496	664	3108	No. 2 - dense	30.2	-	828	3906	-
Average or comments:	30.9	580	746	3108	N.B.O.B.	30.1	-	828	3906	-
3-1	16.1	1001	2327	3148	No. 2 - medium No. 4 - 4 blisters	18.5	-	330	5745	-
3-2	18.8	1001	2327	3148	No. 2 - medium No. 4. - few	16.5	-	330	5745	-
Average or comments:	17.5	1001	2327	3148	N.B.O.B	17.5	-	330	5745	-
4-1	66.4	-	2329	5574	-	64.7	-	100	5574	-
4-2	45.4	-	1333	5574	-	44.9	-	100	5574	-
Average or comments:	55.9	-	1831	5574	-	54.8	-	100	5574	-
5-1	38.3	1494	998	3135	No. 2 - 7 blisters	37.7	2315	333	3135	No. 2 - dense
5-2	36.3	1494	998	3135	No. 2 - 3 blisters	36.7	3135	333	3135	No. 4 - few
Average or comments:	37.3	1494	998	3135	N.B.O.B.	37.2	2725	333	3135	Blisters on backs of panels
6-1	39.7	1826	1163	3135	No. 2 - 2 blisters	41.4	2478	168	3135	No. 2 - dense
6-2	41.6	2153	1163	3135	No. 2 - 1 blister	39.9	2640	333	3135	No. 2 - dense
Average or comments:	40.7	1990	1163	3135	N.B.O.B	40.7	2559	251	3135	Blisters on back of panel panel No. 1
7-1	10.8	4283	165	4449	No. 6 - few	10.1	-	165	4749	-
7-2	10.0	994	1658	3127	No. 4 to 6 - few	10.9	-	165	4749	-
Average or comments:	10.4	2639	912	3788	Blisters on back of panel No. 1, N.B.O.B. panel No. 2	10.5	-	165	4749	Few rust spots, no blisters on backs of panels

(Continued)

(Sheet 1 of 4)

Table 3 (Continued)

System No.-Panel No.	Saltwater immersion: Average Dry-film thickness (mils)	Saltwater immersion: [3] Initial blistering (hours)	Saltwater immersion: [3] 100% rusting in scribe lines (hours)	Saltwater immersion: Total hours completed	Saltwater immersion: [1] Blister size and frequency (completion)	Fresh (deionized)water immersion: Average dry-film thickness (mils)	Fresh (deionized)water immersion: [3] Initial blistering (hours)	Fresh (deionized)water immersion: [3] 100% rusting in scribe lines (hours)	Fresh (deionized)water immersion: Total hours completed	Fresh (deionized)water immersion: [1] Blister size and frequency (completion)
8-1	13.4	-	1984	4749	-	13.0	-	1326	4749	-
8-2	13.5	-	1984	4749	-	12.4	-	165	4749	-
Average or comments:	13.5	-	1984	4749	-	12.7	-	746	4749	Few rust spots, no blisters on back of panel No. 1
9-1	20.5	-	2659	5574	-	21.1	-	327	5574	-
9-2	20.9	-	2659	5574	-	20.1	-	327	5574	-
Average or comments:	20.7	-	2659	5574	-	20.6	-	327	5574	-
10-1	14.5	2946	164	3112	No. 4 - 1 blister	13.9	-	164	3242	-
10-2	14.6	2779	164	3112	No. 4 - 2 blisters	14.3	-	164	3242	-
Average or comments:	14.6	2863	164	3112	N.B.O.B.	14.1	-	164	3242	-
11-1	16.8	670	336	3135	No. 2 - 11 blisters No. 6 - 5 blisters	16.8	-	168	5077	-
11-2	16.0	670	834	3135	No. 2 - 8 blisters No. 4 - medium	16.2	-	168	5077	-
Average or comments:	16.4	670	585	3135	Blisters on backs of panels	16.5	-	168	5077	-
12-1	22.0	1169	503	3133	No. 2 - dense	20.4	-	168	5403	-
12-2	21.3	1169	503	3133	No. 2 - medium	19.8	-	168	5403	-
Average or comments:	21.7	1169	503	3133	Blisters on backs of panels	20.1	-	168	5403	-
13-1	12.9	496	2301	3123	No. 2 - 7 blisters No. 4 - 4 blisters	12.3	-	2139	4407	-
13-2	12.3	1161	2301	2123	No. 2 - 4 blisters No. 4 - 1 blister	13.2	-	2139	4407	-
Average or comments:	12.6	829	2301	3123	N.B.O.B.	12.8	-	2139	4407	-
14-1	6.8	167	1469	3078	No. 4 - dense	6.9	652	167	3078	No. 4 - dense
14-2	7.0	167	1469	3078	No. 4 - dense	6.8	652	167	3078	No. 4 - dense
Average or comments:	6.9	167	1469	3078	Blisters on backs of panels, some rusting	6.9	652	167	3078	Blisters on backs of panels, some rusting

(Continued)

(Sheet 2 of 4)

Table 3 (Continued)

System No.-Panel No.	Saltwater immersion: Average Dry-film thickness (mils)	[3] Initial blistering (hours)	[3] 100% rusting in scribe lines (hours)	Total hours completed	[1] Blister size and frequency (completion)	Fresh (deionized)water immersion: Average dry-film thickness (mils)	[3] Initial blistering (hours)	[3] 100% rusting in scribe lines (hours)	Total hours completed	[1] Blister size and frequency (completion)
15-1	10.6	994	334	3127	No. 2 - 4 blisters	10.6	-	168	4749	-
15-2	10.7	994	168	3127	No. 2 - 5 blisters	10.6	-	168	4749	-
Average or comments:	10.7	994	251	3127	Blisters on back of panel No. 1	10.6	-	168	4749	Rust spots on back of panel No. 1
16-1	26.9	-	1804	3906	-	27.6	-	1969	3906	-
16-2	26.5	-	1804	3906	-	26.2	-	1969	3906	-
Average or comments:	26.7	-	1804	3906	-	26.9	-	1969	3906	-
17-1	26.6	-	1969	3906	-	29.2	-	1804	3906	-
17-2	27.1	-	1804	3906	-	29.5	-	1804	3906	-
Average or comments:	26.9	-	1887	3906	-	29.4	-	1804	3906	-
18-1	9.0	499	332	3115	No. 4 - med. dense	9.0	-	169	3582	-
18-2	8.8	499	332	3115	No. 4 - med. dense	8.8	-	169	3582	-
Average or comments:	8.9	499	332	3115	N.B.O.B.	8.9	-	169	3582	-
19-1	9.7	332	332	3115	No. 2 - medium	8.7	-	499	3582	-
19-2	8.6	332	332	3115	No. 2 - medium	9.6	-	499	3582	-
Average or comments:	9.2	332	332	3115	N.B.O.B.	9.2	-	499	3582	-
20-1	52.6	-	822	3582	-	56.8	-	169	3582	-
20-2	56.7	-	822	3582	-	52.8	-	169	3582	-
Average or comments:	54.7	-	822	3582	-	54.8	-	169	3582	-
21-1	56.4	-	822	3582	-	56.5	-	169	3582	-
21-2	55.2	-	822	3582	-	55.9	-	169	3582	-
Average or comments:	55.8	-	822	3582	-	56.2	-	169	3582	-

(Continued)

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Table 3 (Concluded)

System No.-Panel No.	Saltwater immersion: Average Dry-film thickness (mils)	[3] Initial blistering (hours)	[3] 100% rusting in scribe lines (hours)	Total hours completed	[1] Blister size and frequency (completion)	Fresh (deionized)water immersion: Average dry-film thickness (mils)	[3] Initial blistering (hours)	[3] 100% rusting in scribe lines (hours)	Total hours completed	[1] Blister size and frequency (completion)
22-1	7.6	167	167	3078	No. 4 - few No. 8 - dense	7.7	167	327	3078	No. 8 - dense
22-2	7.1	167	167	3078	No. 4 - few No. 8 - dense	7.0	167	327	3078	No. 8 - dense
Average or comments:	7.4	167	167	3078	Blisters on backs of panels and some rust spots on Panel No. 2	7.4	167	327	3078	Rust spots on backs of panels
23-1	35.6	486	160	3083	No. 2 - 5 blisters no. 4 - few	35.8	-	160	3083	-
23-2	37.1	486	160	3083	No. 2 - 5 blisters No. 4 - 9 blisters	37.6	-	810	3083	-
Average or comments:	36.4	486	160	3083	N.B.O.B.	36.7	-	485	3083	-
24-1	30.8	489	167	3078	No. 2 - few No. 4 - few	29.5	-	167	3078	-
24-2	31.4	1141	167	3078	No. 2 - few No. 4 - few	29.3	-	167	3078	-
Average or comments:	31.1	815	167	3078	N.B.O.B.	29.4	-	167	3078	-

1. Pictorial Standards of Coatings Defects and ASTM: D714-56. The largest number refers to the smallest blisters on a scale of 2-8 (2 - large, 8 - small).

2. N.B.O.B. - No blistering on back of panel or panels.

3. The numbers of hours recorded are the numbers of hours of exposure as of the time the panels were examined. The exact numbers of hours before blistering or rusting took place are unknown. However, in no instance would the number of hours be less than the recorded numbers of hours by more than 1 week's exposure time, approximately 164-168 hours.

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Table 4

Immersion Test Data - Color Change

[1] System No.-Panel No. SW or FW	Average Dry-film thickness (mils)	Hours of Immersion before color was checked	[2] CIE 1976 CIELAB L* a* b* color data: Before Immersion L*	Before Immersion a*	Before Immersion b*	After Immersion L*	After Immersion a*	After Immersion b*	Color difference ΔL*	Color difference Δa*	Color difference Δb*	[3] ΔE*ab	Panel is continuing in Immersion test? Yes	No
1-1 SW	32.0	3148	71.64	-1.18	+2.21	70.43	-6.19	+10.57	-1.21	-5.01	+8.36	9.82		X
1-2 SW	33.4	3148	71.44	-1.05	+1.90	67.84	-5.54	+14.20	-3.60	-4.49	+12.30	13.58		X
Average:	32.7	3148	71.54	-1.12	+2.06	69.14	-5.87	+12.39	-2.41	-4.75	+10.33	11.62		-
1-1 FW	33.0	3148	71.40	-1.19	+2.26	70.35	-6.75	+9.84	-1.05	-5.56	+7.58	9.45	X	
1-2 FW	32.0	3148	71.36	-1.18	+2.31	69.68	-6.95	+12.81	-1.68	-5.77	+10.50	12.10	X	
Average:	32.5	3148	71.38	-1.19	+2.29	70.02	-6.85	+11.33	-1.37	-5.67	+9.04	10.76	-	
2-1 SW	30.5	3108	57.13	-0.71	-0.52	44.03	+2.53	+20.42	-13.10	+3.24	+20.94	24.91		X
2-2 SW	31.3	3108	56.44	-0.63	-0.36	44.37	+1.56	+18.97	-12.07	+2.19	+19.33	22.89		X
Average:	30.9	3108	56.79	-0.67	-0.44	44.20	+2.0[illegible]	+19.70	-12.59	+2.72	+20.14	23.91		-
2-1 FW	30.0	3108	56.75	-0.53	-0.74	53.92	-5.65	+12.09	-2.83	-5.12	+12.83	14.10	X	
2-2 FW	30.2	3108	56.72	-0.56	-0.63	54.66	-5.40	+11.18	-2.06	-4.84	+11.81	12.93	X	
Average:	30.1	3108	56.74	-0.55	-0.69	54.29	-5.53	+11.64	-2.45	-4.98	+12.32	13.51	-	
3-1 SW	16.1	3148	61.25	-22.92	+28.36	60.43	-24.60	+27.28	-0.82	-1.68	-1.08	2.16		X
3-2 SW	18.8	3148	60.90	-23.20	+28.90	59.61	-24.89	+29.70	-1.29	-1.69	-0.80	2.27		X
Average:	17.5	3148	61.08	-23.06	+28.63	60.02	-24.75	+28.49	-1.06	-1.69	-0.94	2.21		-
3-1 FW	18.5	3148	62.14	-22.00	+27.09	60.77	-24.26	+29.01	-1.37	-2.26	+1.92	3.27	X	
3-2 FW	16.5	3148	60.91	-23.05	+28.49	59.99	-22.13	+27.82	-0.92	-0.92	+0.67	1.46	X	
Average:	17.5	3148	61.53	-22.53	+27.79	60.38	-23.20	+28.42	-1.15	-1.59	+1.30	2.35	-	
4-1 SW	66.4	3145	76.74	-0.78	+22.57	71.02	-1.89	+32.41	-5.72	-1.11	+9.84	11.44	X	
4-2 SW	45.4	3145	76.60	-0.48	+22.89	68.42	-0.83	+30.93	-8.18	-0.35	+8.04	11.48	X	
Average:	55.9	3145	76.67	-0.63	+22.73	69.72	-1.36	+31.67	-6.95	-0.73	+8.94	11.35	-	
4-1 FW	64.7	3145	75.71	-0.77	+21.81	71.36	-2.53	+33.74	-4.35	-1.76	+11.93	12.87	X	
4-2 FW	44.9	3145	76.24	-0.73	+22.13	70.90	-2.27	+30.81	-5.34	-1.54	+8.68	10.31	X	
Average:	54.8	3145	75.98	-0.75	+21.97	71.13	-2.40	+32.28	-4.85	-1.65	+10.31	11.51	-	
5-1 SW	38.3	3135	20.44	+0.34	0.00	28.48	-2.65	+0.97	+8.04	-2.99	+0.97	8.63		X
5-2 SW	36.3	3135	20.77	+0.27	+0.10	27.96	-2.86	+0.89	+7.19	-3.13	+0.79	7.88		X
Average:	37.3	3135	20.61	+0.31	+0.05	28.22	-2.76	+0.93	+7.62	-3.06	+0.88	8.26		-
5-1 FW	37.7	3135	20.17	+0.19	+0.41	29.06	-2.79	+2.57	+8.89	-2.98	+2.16	9.62		X
5-2 FW	36.7	3135	20.28	+0.45	+0.30	26.52	-2.63	+1.27	+6.24	-3.08	+0.97	7.03		X
Average:	37.2	3135	20.23	+0.32	+0.36	27.79	-2.71	+1.92	+7.57	-3.03	+1.57	8.30		-

(Continued)

(Sheet 1 of 6)

Table 4 (Continued)

[1] System No.-Panel No. SW or FW	Average Dry-film thickness (mils)	Hours of Immersion before color was checked	[2] CIE 1976 CIELAB L* a* b* color data: Before Immersion L*	a*	b*	After Immersion L*	a*	b*	Color difference ΔL*	Δa*	Δb*	[3] ΔE*ab	Panel is continuing in immersion test? Yes	No
6-1 SW	39.7	3135	91.48	-1.17	+0.85	90.70	-7.01	+5.51	-0.78	-5.84	+4.66	7.51		X
6-2 SW	41.6	3135	91.13	-1.15	+0.99	82.16	-4.68	+19.41	-8.97	-3.53	+18.42	20.79		X
Average:	40.7	3135	91.31	-1.16	+0.92	86.43	-5.85	+12.46	-4.88	-4.69	+11.54	13.38		-
6-1 FW	41.4	3135	91.18	-1.05	+0.76	90.56	-7.41	+7.60	-0.62	-6.36	+6.84	9.36		X
6-2 FW	39.9	3135	90.27	-1.20	-0.19	89.13	-7.45	+5.87	-1.14	-6.25	+6.06	8.78		X
Average:	40.7	3135	90.73	-1.13	+0.29	89.85	-7.43	+6.74	-0.88	-6.31	+6.45	9.07		-
7-1 SW	10.8	3127	55.94	-1.73	-5.08	53.17	-6.13	-7.95	-2.77	-4.40	+13.03	14.03		X
7-2 SW	10.0	3127	53.77	-1.61	-4.66	53.18	-6.17	-0.60	-0.59	-4.56	+4.06	6.13		X
Average:	10.4	3127	54.86	-1.67	-4.87	53.18	-6.15	+3.68	-1.68	-4.48	+8.55	9.80		-
7-1 FW	10.1	3127	53.34	-1.49	-4.72	51.09	-6.22	+2.63	-2.25	-4.73	+7.35	9.03	X	
7-2 FW	10.9	3127	55.72	-1.76	-4.92	52.25	-6.14	+3.17	-3.47	-4.38	+8.09	9.83	X	
Average:	10.5	3127	54.53	-1.63	-4.82	51.67	-6.18	+2.90	-2.86	-4.56	+7.72	9.41	-	
8-1 SW	13.4	3127	55.77	-1.71	-5.17	56.35	-6.51	-1.18	+0.58	-4.80	+3.99	6.27	X	
8-1 SW	13.6	3127	55.64	-1.61	-5.03	55.31	-6.32	-0.44	-0.33	-4.71	+4.59	6.58	X	
Average:	13.5	3127	55.71	-1.66	-5.10	55.83	-6.42	-0.81	+0.13	-4.76	+4.29	6.41	-	
8-1 FW	13.0	3127	56.07	-1.72	-5.17	54.64	-6.51	-0.17	-1.43	-4.79	+5.00	7.07	X	
8-2 FW	12.4	3127	55.79	-1.68	-4.98	55.64	-6.53	-0.46	-0.15	-4.85	+4.52	6.63	X	
Average:	12.7	3127	55.93	-1.70	-5.08	55.14	-6.52	-0.32	-0.79	-4.82	+4.76	6.82	-	
9-1 SW	20.5	3145	22.28	+0.77	+0.10	24.06	-1.59	+1.56	+1.78	-2.36	+1.46	3.30	X	
9-2 SW	20.9	3145	21.76	+0.82	-0.06	24.22	-1.60	+1.52	+2.46	-2.42	+1.58	3.80	X	
Average:	20.7	3145	22.02	+0.80	+0.02	24.14	-1.60	+1.54	+2.12	-2.39	+1.52	3.54	-	
9-1 FW	21.1	3145	23.16	+0.81	-0.22	24.91	-1.70	+1.13	+1.75	-2.51	+1.35	3.34	X	
9-2 FW	20.1	3145	23.73	+0.72	-0.31	25.89	-1.76	+1.47	+2.16	-2.48	+1.78	3.74	X	
Average:	20.6	3145	23.45	+0.77	-0.27	25.40	-1.73	+1.30	+1.96	-2.50	+1.57	3.54	-	
10-1 SW	14.5	3112	58.99	-0.02	+1.04	60.96	-4.42	+4.75	+1.97	-4.42	+3.71	6.10		X
10-2 SW	14.6	3112	59.67	-0.22	+1.27	63.07	-4.99	+5.47	+3.40	-4.77	+4.20	7.21		X
Average:	14.6	3112	59.33	-0.12	+1.16	62.02	-4.71	+5.11	+2.69	-4.60	+3.96	6.64		-
10-1 FW	13.9	3112	59.18	-0.24	+1.27	62.11	-5.04	+6.27	+2.93	-4.80	+5.00	7.52	X	
10-2 FW	14.3	3112	59.71	-0.32	+1.36	62.75	-4.97	+5.93	+3.04	-4.65	+4.57	7.19	X	
Average:	14.1	3112	59.45	-0.28	+1.32	62.43	-5.01	+6.10	+2.99	-4.73	+4.79	7.37	-	

(Continued)

(Sheet 2 of 6)

Table 4 (Continued)

[1] System No.-Panel No. SW or FW	Average Dry-film thickness (mils)	Hours of immersion before color was checked	[2] CIE 1976 CIELAB L* a* b* color data: Before immersion L*	a*	b*	After immersion L*	a*	b*	Color difference ΔL*	Δa*	Δb*	[3] ΔE*ab	Panel is continuing in immersion test? Yes	No
11-1 SW	16.8	3135	63.38	-1.19	+1.34	60.10	-5.31	+13.29	-3.28	-4.12	+11.95	13.06		X
11-2 SW	16.0	3135	63.22	-1.11	+1.46	58.12	-4.57	+13.89	-5.10	-3.46	+12.43	13.87		X
Average:	16.4	3135	63.30	-1.15	+1.40	59.11	-4.94	+13.59	-4.19	-3.79	+12.19	13.44		-
11-1 FW	16.8	3135	63.74	-1.13	+1.53	61.37	-6.17	+11.67	-2.37	-5.94	+10.14	11.57	X	
11-2 FW	16.2	3135	63.81	-1.14	+1.45	62.58	-6.93	+10.31	-1.23	-5.79	+8.86	10.66	X	
Average:	16.5	3135	63.78	-1.14	+1.49	61.98	-6.55	+10.99	-1.80	-5.42	+9.50	11.08	-	
12-1 SW	22.0	3133	25.41	+0.56	-0.05	29.11	-2.32	+2.32	+3.70	-2.88	+2.37	5.25		X
12-2 SW	21.3	3133	22.36	+0.81	+0.32	27.96	-1.98	+3.12	+5.60	-2.79	+2.80	6.85		X
Average:	21.7	3133	23.89	+0.69	+0.14	28.54	-2.15	+2.72	+4.65	-2.84	+2.59	6.03		-
12-1 FW	20.4	3133	25.30	+0.53	-0.02	26.87	-2.17	+1.76	+1.57	-2.70	+1.78	3.59	X	
12-2 FW	19.8	3133	25.20	+0.96	-0.14	27.52	-2.02	+2.18	+2.32	-2.98	+2.32	4.43	X	
Average:	20.1	3133	25.25	+0.75	-0.08	27.20	-2.10	+1.97	+1.95	-2.84	+2.05	4.01	-	
13-1 SW	12.9	3123	92.22	-1.25	+3.28	77.64	-4.37	+23.25	-14.58	-3.12	+19.97	24.92		X
13-2 SW	12.3	3123	92.19	-1.25	+3.25	78.69	-2.15	+30.05	-13.50	-0.90	+26.80	30.02		X
Average:	12.6	3123	92.21	-1.25	+3.27	78.17	-3.26	+26.65	-14.04	-2.01	+23.39	27.35		-
13-1 FW	12.3	3123	92.10	-1.25	+3.34	85.00	-7.32	+21.51	-7.10	-6.07	+18.17	20.43	X	
13-2 FW	13.2	3123	92.12	-1.17	+3.27	81.47	-6.27	+20.44	-10.65	-5.10	+17.17	20.84	X	
Average:	12.8	3123	92.11	-1.21	+3.31	83.24	-6.80	+20.98	-8.88	-5.59	+17.67	20.55	-	
14-1 SW	6.8	3078	54.02	-0.37	-2.32	47.87	-2.53	+17.74	-6.15	-2.16	+20.06	21.09		X
14-2 SW	7.0	3078	52.48	-0.28	-2.44	44.63	-2.76	+14.24	-7.85	-2.48	+16.68	18.60		X
Average:	6.9	3078	53.25	-0.33	-2.38	46.25	-2.65	+15.99	-7.00	-2.32	+18.37	19.79		-
14-1 FW	6.9	3078	54.29	-0.36	-2.42	44.94	+0.89	+23.26	-9.35	+1.25	+25.68	27.36		X
14-2 FW	6.8	3078	53.73	-0.34	-2.29	49.70	-0.41	+24.12	-4.03	-0.07	+26.41	26.72		X
Average:	6.9	3078	54.01	-0.35	-2.36	47.32	+0.24	+23.69	-6.69	+0.59	+26.05	26.90		-
15-1 SW	10.6	3127	49.07	-0.33	-3.78	48.48	-4.43	+1.30	-0.59	-4.10	+5.08	6.55		X
15-2 SW	10.7	3127	49.65	-0.28	-3.73	49.28	-4.50	+1.02	-0.37	-4.22	+4.75	6.36		X
Average:	10.7	3127	49.36	-0.31	-3.76	48.88	-4.47	+1.16	-0.48	-4.16	+4.92	6.46		-
15-1 FW	10.6	3127	48.93	-0.18	-3.69	48.37	-4.35	+6.57	-0.56	-4.17	+10.26	11.09	X	
15-2 FW	10.6	3127	49.76	-0.25	-3.67	49.88	-4.47	+3.66	-0.12	-4.22	+7.33	8.46	X	
Average:	10.6	3127	49.35	-0.22	-3.68	49.13	-4.41	+5.12	-0.34	-4.20	+8.80	9.76	-	

(Continued)

(Sheet 3 of 6)

Table 4 (Continued)

[1] System No.-Panel No. SW or FW	Average Dry-film thickness (mils)	Hours of Immersion before color was checked	[2] CIE 1976 CIELAB L* a* b* color data: Before Immersion L*	Before Immersion a*	Before Immersion b*	After Immersion L*	After Immersion a*	After Immersion b*	Color difference ΔL*	Color difference Δa*	Color difference Δb*	[3] ΔE*ab	Panel is continuing in immersion test? Yes	No
16-1 SW	26.9	3108	90.09	-0.32	+5.15	80.42	+3.81	+25.18	-9.67	+4.13	+20.03	22.62	x	
16-2 SW	26.5	3108	89.23	-0.65	+2.58	87.26	-0.09	+14.56	-1.97	+0.56	+11.98	12.15	x	
Average:	26.7	3108	89.66	-0.49	+3.87	83.84	+1.86	+19.87	-5.82	+2.35	+16.01	17.20	-	
16-1 FW	27.6	3108	87.52	-1.32	+3.30	88.01	-1.52	+13.04	+0.49	-0.20	+9.74	9.75	x	
16-2 FW	26.2	3108	89.81	-1.09	+4.11	89.54	-1.81	+12.64	-0.27	-0.72	+8.53	8.56	x	
Average:	26.9	3108	88.67	-1.21	+3.71	88.78	-1.67	+12.84	+0.11	-0.46	+9.14	9.15	-	
17-1 SW	26.6	3108	88.21	-1.08	+4.01	83.28	-4.58	+21.11	-4.93	-3.50	+17.10	18.14	x	
17-2 SW	27.1	3108	87.21	-0.95	+3.67	78.42	-4.26	+21.43	-8.79	-3.31	+17.76	20.09	x	
Average:	26.9	3108	87.71	-1.02	+3.84	80.85	-4.42	+21.27	-6.86	-3.41	+17.43	19.04	-	
17-1 FW	29.2	3108	89.64	-0.78	+5.67	86.47	-6.74	+19.76	-3.17	-5.96	+14.09	15.62	x	
17-2 FW	29.5	3108	88.15	-1.07	+3.92	87.58	-7.48	+17.46	-0.57	-6.41	+13.54	14.99	x	
Average:	29.4	3108	88.90	-0.93	+4.80	87.03	-7.11	+18.61	-1.87	-6.19	+13.82	15.26	-	
18-1 SW	9.0	3115	95.35	-1.03	+1.06	69.98	-3.19	+24.59	-25.37	-2.16	+23.53	34.67		x
18-2 SW	8.8	3115	95.30	-1.03	+1.21	66.13	-2.84	+21.77	-29.17	-1.81	+20.56	35.73		x
Average:	8.9	3115	95.33	-1.03	+1.14	68.06	-3.02	+23.18	-27.27	-1.99	+22.05	35.13		-
18-1 FW	9.0	3115	95.61	-1.10	+1.25	66.75	-2.62	+26.77	-28.86	-1.52	+25.52	38.55	x	
18-2 FW	8.8	3115	92.11	-1.02	+0.94	64.93	-3.65	+20.96	-27.18	-2.63	+20.02	33.86	x	
Average:	8.9	3115	93.86	-1.06	+1.10	65.84	-3.14	+23.87	-28.02	-2.08	+22.77	36.17	-	
19-1 SW	9.7	3115	76.35	-5.75	-7.32	61.98	-6.29	+18.84	-14.37	-0.54	+26.16	29.85		x
19-2 SW	8.6	3115	73.31	-5.26	-7.61	59.43	-7.57	+13.74	-13.88	-2.31	+21.35	25.57		x
Average:	9.2	3115	74.83	-5.51	-7.47	60.71	-6.93	+16.29	-14.13	-1.43	+23.76	27.68		-
19-1 FW	8.7	3115	76.79	-5.38	-7.93	63.78	-9.58	+11.28	-13.01	-4.20	+19.21	23.58	x	
19-2 FW	9.6	3115	76.07	-5.70	-7.18	63.49	-9.63	+12.16	-12.58	-3.93	+19.34	23.40	x	
Average:	9.2	3115	76.43	-5.54	-7.56	63.64	-9.61	+11.72	-12.80	-4.07	+19.28	23.50	-	

(Continued)

(Sheet 4 of 6)

Table 4 (Continued)

[1] System No.-Panel No. SW or FW	Average Dry-film thickness (mils)	Hours of immersion before color was checked	[2] CIE 1976 CIELAB L* a* b* color data: Before immersion L*	a*	b*	After immersion L*	a*	b*	Color difference ΔL*	Δa*	Δb*	[3] ΔE*ab	Panel is continuing in immersion test? Yes	No
20-1 SW	52.6	3115	74.61	-0.13	+21.04	65.93	-0.54	+24.46	-8.68	-0.41	+3.42	9.34	X	
20-2 SW	56.7	3115	74.87	-0.26	+20.98	70.01	-1.64	+23.39	-4.86	-1.38	+2.41	5.60	X	
Average:	54.7	3115	74.74	-0.20	+21.01	67.97	-1.09	+23.93	-6.77	-0.90	+2.92	7.43	-	
20-1 FW	56.8	3115	74.73	-0.07	+20.96	71.68	-2.46	+21.96	-3.05	-2.39	+1.00	4.00	X	
20-2 FW	52.8	3115	73.29	-0.14	+21.57	69.65	-0.63	+28.01	-3.64	-0.49	+6.44	7.41	X	
Average:	54.8	3115	74.01	-0.11	+21.27	70.67	-1.55	+24.99	-3.35	-1.44	+3.72	5.21	-	
21-1 SW	56.4	3115	74.55	-0.02	+20.83	69.91	-1.28	+23.19	-4.64	-1.26	+2.36	5.36	X	
21-2 SW	55.2	3115	75.37	+0.07	+20.44	68.69	-0.79	+23.89	-6.68	-0.86	+3.45	7.57	X	
Average:	55.8	3115	74.96	+0.03	+20.64	69.30	-1.04	+23.54	-5.66	-1.06	+2.91	6.45	-	
21-1 FW	56.5	3115	74.77	0.00	+20.14	72.77	-2.22	+21.47	-2.00	-2.22	+1.33	3.27	X	
21-2 FW	56.9	3115	74.67	-0.09	+20.89	73.41	-2.61	+22.12	-1.26	-2.52	+1.23	3.07	X	
Average:	56.2	3115	74.72	-0.05	+20.52	73.09	-2.42	+21.80	-1.63	-2.37	+1.28	3.15	-	
22-1 SW	7.6	3078	38.94	+24.57	+16.24	38.11	+16.48	+17.33	-0.83	-8.09	-1.09	8.21		X
22-2 SW	7.1	3078	38.43	+25.03	+17.33	37.72	+16.36	+17.43	-0.71	-8.67	-0.10	8.70		X
Average:	7.4	3078	38.69	+24.80	+16.79	37.92	+16.42	+17.38	-0.77	-8.38	-0.60	8.44		-
22-1 FW	7.7	3078	38.45	+24.80	+16.56	38.11	+14.26	+14.13	-0.34	-10.54	-2.43	10.82		X
22-2 FW	7.0	3078	38.63	+24.81	+16.46	36.99	+12.45	+12.82	-1.64	-12.36	-3.64	12.99		X
Average:	7.4	3078	38.54	+24.81	+16.51	37.55	+13.36	+13.48	-0.99	-11.45	-3.04	11.89		-
23-1 SW	35.6	3083	65.07	-0.31	-0.64	61.54	-4.85	+12.11	-3.53	-4.54	+12.75	13.99		X
23-2 SW	37.1	3083	65.68	-0.28	-0.62	62.92	-5.10	+12.12	-2.76	-4.82	+12.74	13.90		-
Average:	36.4	3083	66.38	-0.30	-0.63	62.23	-4.98	+12.12	-3.15	-4.68	+12.75	13.94		-
23-1 FW	35.8	3083	66.31	-0.37	-0.60	64.39	-5.96	+8.65	-1.92	-5.59	+9.25	10.98	X	
23-2 FW	37.6	3083	65.57	-0.31	-0.60	64.83	-6.19	+9.50	-0.74	-5.88	+10.10	11.71	X	
Average:	36.7	3083	65.94	-0.34	-0.60	64.61	-6.08	+9.08	-1.33	-5.74	+9.68	11.33	-	

(Continued)

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Table 4 (Concluded)

[1] System No.-Panel No. SW or FW	Average Dry-film thickness (mils)	Hours of immersion before color was checked	[2] CIE 1976 CIELAB L* a* b* color data: Before Immersion L*	a*	b*	After Immersion L*	a*	b*	Color difference ΔL*	Δa*	Δb*	[3] ΔE*ab	Panel is continuing in immersion test? Yes	No
24-1 SW	30.8	3078	56.86	-0.51	-0.84	40.64	+4.08	+18.44	-16.22	+4.59	+19.28	25.61		X
24-2 SW	31.4	3078	56.53	-0.41	-0.97	41.44	+4.39	+19.65	-15.09	+4.80	+20.62	26.00		X
Average:	31.1	3078	56.70	-0.46	-0.91	41.04	+4.24	+19.05	-15.66	+4.70	+19.95	25.79		-
24-1 FW	29.5	3078	56.50	-0.43	-0.91	54.09	-4.89	+9.59	-2.41	-4.46	+10.50	11.66	X	
24-2 FW	29.3	3078	56.00	-0.39	-0.78	54.86	-4.85	+8.86	-1.14	-4.46	+9.64	10.68	X	
Average:	29.4	3078	56.25	-0.41	-0.85	54.48	-4.87	+9.23	-1.78	-4.46	+10.07	11.16	-	

Notes

1. SW = Saltwater FW= Fresh (Deionized) water.

2. The CIE 1976 CIELAB L* a* b* Color Data System is based on a three-dimensional color mapping system. The L*, or lightness, axis is perpendicular to the +a* (red), -a* (green), +b* (yellow), and -b* (blue) axes.

3. The total color difference, ΔE*ab, was calculated using the method given in ASTM: D2244-85. The equation used to calculate ΔE^*_{ab} is:

$$\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

4. For a discussion of Illuminant C, consult Note No. 1 of Table No. 5.

5. Panels which did not blister during the basic immersion period, which coincided with the "Hours of immersion before color was checked" column, are being continued in the saltwater and/or the fresh (deionized) water immersion tests.

(Sheet 6 of 6)

Table 5

Summary of Test Data

System No.	[1] Total target dry-film thickness	Saltwater immersion: [8] Initial blistering (hours)	Saltwater immersion: Total hours compld.	Saltwater immersion: [2] Total color diff (E*ab)	Saltwater immersion: Pull-off adhesion (lb/in²)	Fresh (Deion.) water immersion: [8] Initial blistering (hours)	Fresh (Deion.) water immersion: Total hours compld.	Fresh (Deion.) water immersion: [2] Total color diff. (ΔE*ab)	Fresh (Deion.) water immersion: Pull-off adhesion (lb/in²)	QUV Acc weathering: [3] Chalk rating compltd.	QUV Acc weathering: [2] Total color diff. (ΔE*ab)	QUV Acc weathering: Pull-off adhesion (lb/in²)	Adhesion Pull-off adhesion-control (lb/in²)	1-inch Mandrel: Cracking Yes	1-inch Mandrel: Cracking No	1-inch Mandrel: Some loss of adhesion Yes	1-inch Mandrel: Some loss of adhesion No	General coating properties: [1] Min. number coats	General coating properties: [1] Min. curing Time at 75 F before immersion (days) [1,4,5]	General coating properties: Method of applctn.	[6] Type of coating: LS	Type of coating: HS	Type of coating: HP	Type of coating: R3
1	30	1001	3148	11.62	658	[6] CIT	5745	10.76	CIT	8	29.34	613	800		X		X	2	4	C, A, PCH	P	-	T	-
2	30	580	3108	23.91	535	CIT	3906	13.51	CIT	6	8.20	395	392		X		X	3	4	C, A, PC	P	T	-	-
3	16	1001	3148	2.21	170	CIT	5745	2.35	CIT	8	22.42	195	180	X		X		2	3	PC	-	SP	-	-
4	50	CIT	5574	11.35	CIT	CIT	5574	11.51	CIT	9	11.68	298	403		X		X	1	3	PCH	-	-	SP	-
5	35-36	1494	3135	8.26	138	2725	3135	8.30	154	6	2.65	355	300		X		X	2	1	C, A	P	T	-	-
6	37-39	1990	3135	13.38	298	2559	3135	9.07	154	10	9.01	463	300	X			X	4	4	C, A	P	I,T	-	-
7	9	2639	3788	9.80	198	CIT	4749	9.41	CIT	6	11.93	102	197		X		X	3	4	C, A	-	P,T	-	-
8	9	CIT	4749	6.41	CIT	CIT	4749	6.82	CIT	8	12.77	90	190	X		X		3	4	C, A	P	I,T	-	-
9	20	CIT	5574	3.54	CIT	CIT	5574	3.54	CIT	8	4.57	315	363	X			X	2	1	PC (spec.)	-	-	SP	-
10	9-13	2863	3112	6.64	164	CIT	3242	7.37	CIT	4	18.50	165	93	X			X	2	5	B, C, A	-	P,T	-	-
11	16	670	3135	13.44	154	CIT	5077	11.08	CIT	4	10.75	143	268	X			X	2	7	C, A	-	SP	-	-
12	20	1169	3133	6.03	205	CIT	5403	4.01	CIT	6	20.71	185	308	X			X	1	3	PCH	-	-	SP	-
13	12	829	3123	27.35	145	CIT	4407	20.55	CIT	4	10.14	103	97	X			X	2	2	C, A	-	SP	-	-
14	8	167	3078	19.79	243	652	3078	26.90	200	4	13.76	65	327		X		X	1	7	C, A, AAA	-	-	-	SP
15	10	994	3127	11.62	245	CIT	4749	10.76	CIT	8	7.28	248	250		X		X	6	10	C, A	P, I,T	-	-	-
16	26-34	CIT	3906	17.20	CIT	CIT	3906	9.15	CIT	6	8.87	123	313	X			X	4	0.08	B, R, PPC, A	-	-	P,I, T	-
17	26-34	CIT	3906	19.04	CIT	CIT	3906	15.26	CIT	6	13.48	163	333	X			X	4	0.08	B, R, PPC, A HHAAA	-	-	P,I, T	-
18	6-9	499	3115	35.13	153	CIT	3582	36.17	CIT	6	13.81	119	163	X			X	5	7	C, A	-	P,I, T	-	-
19	8-10	332	3115	27.68	132	CIT	3582	23.50	CIT	6	13.77	98	233	X			X	2	7	C, A	-	P,T	-	-
20	55-56	CIT	3582	7.43	CIT	CIT	3582	5.21	CIT	4	18.90	130	285	X		X		3	2	G45A	-	P	I,T	-

(Continued)

(Sheet 1 of 2)

Table 5 (Concluded)

System No.	[1] Total target dry-film thickness	Saltwater immersion: [8] Initial blistering (hours)	Saltwater immersion: Total hours compld	Saltwater immersion: [1] Total color diff. (ΔE^*ab)	Saltwater immersion: Pull-off adhesion (lb/in^2)	Fresh (Deion.) water immersion: [8] Initial blistering (hours)	Fresh (Deion.) water immersion: Total hours compld.	Fresh (Deion.) water immersion: [2] Total color diff. (ΔE^*ab)	Fresh (Deion.) water immersion: Pull-off adhesion (lb/in^2)	QUV Acc weathering: [3] Chalk rating compld.	QUV Acc weathering: [2] Total color diff. (ΔE^*ab)	QUV Acc weathering: Pull-off adhesion (lb/in^2)	Adhesion Pull-off adhesion-control (lb/in^2)	1-inch Mandrel: Cracking Yes	1-inch Mandrel: Cracking No	1-inch Mandrel: Some loss of adhesion Yes	1-inch Mandrel: Some loss of adhesion No	General coating properties: [1] Min. number coats	General coating properties: [1] Min. curing time at 75°F before immersion (days)	General coating properties: [1,4,5] Method of applctn.	General coating properties: [6] Type of coating LS	HS	HP	WB
21	55 56	CIT	3582	6.45	CIT	CIT	3582	3.15	CIT	4	17.10	213	330	X		X		4	2	G45A	PR	P	I,T	-
22	6	167	3078	8.44	170	167	3078	11.89	207	6	28.46	105	200		X		X	3	7	C,A	-	-	-	SP
23	32	486	3083	13.94	243	CIT	3083	11.33	CIT	6	15.00	625	427		X		X	2	4	C, A, PCH	P	-	T	-
24	32	815	3078	25.79	478	CIT	3078	11.16	CIT	8	10.42	510	483		X		X	3	4	C, A, PC	P	T	-	-

Notes

1. The values or information in these columns were supplied by the manufacturers of the coatings.

2. The total color differences, ΔE^*ab, were computed from the Illuminant C readings. These readings were taken before immersion and exposure and at the end of the basic 3000-hours immersion and exposure periods.

3. The chalk ratings are based on the visual scales in Pictorial Standards of Coatings Defects. A rating of 2 on the 2, 4, 6, 8, and 10 scale refers to very heavy chalking, while a rating of 10 refers to an absence of chalking.

4. C = conventional spray, A = airless spray, PCH = plural component (heated) spray. PC = plural component spray, PC (spec.) = special plural component spray. B = brush, AAA = air assisted airless spray, R = roller, PPC = pressure pot conventional spray, HHAAA = heavy duty high pressure air assisted airless spray, G45 = Graco 45 airless spray.

5. For more complete information on the equipment required or permitted for the application of specific coats, refer to table No. 2. The manufacturer of the specific coating to be used on a hydraulic (or any) structure should be consulted to obtain specific application information for that particular structure.

6. LS = low solids, HS = high solids, HP = 100 percent solids, WB = water borne, P = primer, T = topcoat, SP = self priming, I = intermediate coat, PR = pretreatment.

7. CIT = continuing in test.

8. The numbers of hours recorded are the numbers of hours of exposure as of the time the panels were examined. The exact numbers of hours before initial blistering took place are unknown. However, in no instance would the numbers of hours be less than the recorded numbers of hours by more than 1 week's exposure time, approximately 164-168 hours.

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Table 6

QUV Accelerated Weathering Test Data

System No.-Panel No.	[1] Illum-inant	[2] Average Dry-film thickness (mils)	[6] Initial chalking (hours)	[6] 100% rusting in scribe lines (hours)	Total hours completed	[3] Chalk rating (completion)	[4] CIE 1976 CIELAB L* a* b* color data: Before exposure L*	Before exposure a*	Before exposure b*	After exposure L*	After exposure a*	After exposure b*	After exposure L*	After exposure a*	After exposure b*	After exposure E^*_{ab}
1-1	C	32.0	165	165	3148	8	70.64	-1.20	+2.29	58.73	-0.47	+29.09	-11.91	+0.73	+26.80	29.34
1-2	C	32.0	165	165	3148	8	71.33	-1.05	+1.89	61.07	-1.82	+29.41	-10.26	-0.77	+27.52	29.38
Average:	C	32.0	165	165	3148	8	70.99	-1.13	+2.09	59.90	-1.15	+29.25	-11.09	-0.02	+27.16	29.34
1-1	D65	32.0	165	165	3148	8	70.33	-1.17	+2.24	59.13	+3.75	+26.20	-11.20	+4.92	+23.96	26.90
1-2	D65	32.0	165	165	3148	8	71.33	-1.06	+1.92	60.85	+2.63	+26.65	-10.48	+3.69	+24.73	27.11
Average:	D65	32.0	165	165	3148	8	70.83	-1.12	+2.08	59.99	+3.19	+26.43	-10.84	+4.31	+24.35	27.00
2-1	C	28.9	1155	828	3108	6	57.29	-0.71	-0.52	65.37	-1.19	+0.63	+8.08	-0.48	+1.15	8.18
2-2	C	29.9	1155	828	3108	6	56.75	-0.69	-0.46	64.87	-1.17	+0.73	+8.12	-0.48	+1.19	8.22
Average:	C	29.4	1155	828	3108	6	57.02	-0.70	-0.49	65.12	-1.18	+0.68	+8.10	-0.48	+1.17	8.20
2-1	D65	28.9	1155	828	3108	6	57.32	-0.77	-0.58	65.29	-5.75	+4.15	+7.97	-4.98	+4.73	10.52
2-2	D65	29.9	1155	828	3108	6	56.93	-0.71	-0.52	65.20	-5.74	+4.20	+8.27	-5.03	+4.72	10.77
Average:	D65	29.4	1155	828	3108	6	57.13	-0.74	-0.55	65.25	-5.75	+4.18	+8.12	-5.01	+4.73	10.65
3-1	C	16.8	165	165	3148	8	60.89	-23.17	+28.86	69.86	-11.26	+14.33	+8.97	+11.91	-19.89	24.86
3-2	C	17.4	165	165	3148	8	60.88	-23.44	+29.24	68.48	-11.39	+15.06	+7.60	+12.05	-14.18	20.10
Average:	C	17.1	165	165	3148	8	60.88	-23.31	+29.05	69.17	-11.33	+14.70	+8.29	+11.98	-17.04	22.42
3-1	D65	16.8	165	165	3148	8	60.93	-22.75	+28.91	69.13	-6.53	+11.19	+8.20	+16.22	-17.72	25.38
3-2	D65	17.4	165	165	3148	8	61.03	-22.97	+29.26	68.46	-6.72	+11.66	+7.43	+16.25	-17.60	25.08
Average:	D65	17.1	165	165	3148	8	60.98	-22.86	+29.09	68.80	-6.63	+11.43	+7.82	+16.24	-17.66	25.23
4-1	C	53.9	2819	164	3145	9	77.43	-0.71	+22.70	70.12	+1.94	+27.49	-7.31	+2.65	+4.79	9.13
4-2	C	54.9	2819	164	3145	9	77.07	-0.76	+22.49	67.96	+2.60	+33.19	-9.11	+3.36	+10.70	14.45
Average:	C	54.4	2819	164	3145	9	77.25	-0.74	+22.60	69.04	+2.27	+30.34	-8.21	+3.01	+7.74	11.68
4-1	D65	53.9	2819	164	3145	9	77.61	-0.19	+22.69	70.03	+7.09	+24.50	-7.58	+7.28	+1.81	10.66
4-2	D65	54.9	2819	164	3145	9	77.40	-0.25	+22.47	67.62	+7.82	+30.90	-9.78	+8.07	+8.43	15.23
Average:	D65	54.4	2819	164	3145	9	77.51	-0.22	+22.58	68.83	+7.46	+27.70	-8.68	+7.68	+5.12	12.67
5-1	C	39.7	1993	1993	3135	6	20.82	+0.32	+0.17	18.97	-1.50	+1.39	-1.85	-1.82	+1.22	2.87
5-2	C	38.1	1993	1993	3135	6	19.90	+0.52	-0.11	19.49	-1.69	+1.27	-0.41	-2.21	+1.38	2.84
Average:	C	38.9	1993	1993	3135	6	20.36	+0.42	+0.03	19.23	-1.60	+1.33	-1.13	-2.02	+1.30	2.65
5-1	D65	39.7	1993	1993	3135	6	20.44	+0.38	+0.22	18.96	+0.30	-0.28	-1.48	-0.08	-0.50	1.56
5-2	D65	38.1	1993	1993	3135	6	20.75	+0.45	-0.18	19.42	+0.17	+0.10	-1.33	-0.28	+0.28	1.39
Average:	D65	38.9	1993	1993	3135	6	21.26	+0.42	+0.02	19.19	+0.24	-0.09	-2.07	-0.18	-0.11	2.08

(Continued)

(Sheet 1 of 5)

Table 6 (Continued)

System No.-Panel No.	[1] Illum-inant	[2] Average Dry-film thickness (mils)	[6] Initial chalking (hours)	[6] 100% rusting in scribe lines (hours)	Total hours completed	[3] Chalk rating (completion)	[4] CIE 1976 CIELAB L* a* b* color data: Before exposure L*	Before exposure a*	Before exposure b*	After exposure L*	After exposure a*	After exposure b*	L*	a*	b*	E*ab
6-1	C	47.5	-	666	3135	10	91.31	-1.14	+0.67	89.35	-7.08	+6.48	-1.96	-5.94	+5.81	8.54
6-2	C	47.6	-	666	3135	10	91.39	-1.13	+1.03	88.22	-7.10	+7.71	-3.17	-5.97	+6.68	9.50
Average:	C	47.6	-	666	3135	10	91.35	-1.14	+0.85	88.79	-7.09	+7.10	-2.57	-5.96	+6.25	9.01
6-1	D65	47.5	-	666	3135	10	91.51	-1.21	+0.64	89.65	-1.18	+1.91	-1.86	+0.03	+1.27	2.25
6-2	D65	47.6	-	666	3135	10	91.50	-1.19	+0.94	86.76	-1.17	+3.49	-4.74	+0.02	+2.55	5.38
Average:	D65	47.6	-	666	3135	10	91.51	-1.20	+0.79	88.21	-1.18	+2.70	-3.30	+0.03	+1.91	3.81
7-1	C	10.1	994	168	3127	6	55.58	-1.74	-5.02	64.88	-6.52	-0.78	+9.30	-4.78	+4.24	11.28
7-2	C	12.0	994	168	3127	6	55.78	-1.72	-5.12	66.55	-6.82	-1.09	+10.77	-5.10	+4.03	12.58
Average:	C	11.1	994	168	3127	6	55.68	-1.73	-5.07	65.72	-6.67	-0.94	+10.04	-4.94	+4.14	11.93
7-1	D65	10.1	994	168	3127	6	55.80	-2.03	-5.03	65.19	-1.96	-4.17	+9.39	+0.07	+0.86	9.43
7-2	D65	12.0	994	168	3127	6	55.82	-1.94	-5.15	66.15	-2.23	-5.00	+10.33	-0.29	+0.15	10.34
Average:	D65	11.1	994	168	3127	6	55.81	-1.99	-5.09	65.67	-2.10	-4.59	+9.86	-0.11	+0.51	9.87
8-1	C	12.7	1326	665	3127	8	55.83	-1.80	-5.02	66.02	-6.66	-0.76	+10.19	-4.86	+4.26	12.07
8-2	C	14.8	1326	665	3127	8	55.86	-1.68	-5.19	67.50	-6.49	-0.42	+11.64	-4.81	+4.77	13.47
Average:	C	13.8	1326	665	3127	8	55.85	-1.74	-5.11	66.76	-6.58	-0.59	+10.92	-4.84	+4.52	23.77
8-1	D65	12.7	1326	665	3127	8	56.24	-1.94	-5.09	66.06	-2.16	-4.33	+9.82	-0.22	+0.76	9.85
8-2	D65	14.8	1326	665	3127	8	55.71	-1.91	-5.29	67.90	-2.16	-4.25	+12.19	-0.25	+1.04	12.24
Average:	D65	13.8	1326	665	3127	8	55.51	-1.93	-5.19	66.98	-2.16	-4.29	+11.01	-0.24	+0.90	11.05
9-1	C	23.5	164	332	3145	8	24.04	+0.34	+0.39	27.26	-1.69	+2.11	+3.22	-2.03	+1.72	4.18
9-2	C	21.7	164	332	3145	8	23.20	+0.88	-0.14	26.74	-1.53	+2.39	+3.54	-2.41	[illegible]	4.97
Average:	C	22.6	164	332	3145	8	23.62	+0.61	+0.13	27.00	-1.61	+2.25	+3.38	-2.22	[illegible]	4.57
9-1	D65	23.5	164	332	3145	8	22.80	+0.48	+0.55	27.33	+0.77	+0.23	+4.53	+0.29	-0.25	4.55
9-2	D65	21.7	164	332	3145	8	23.07	+0.85	-0.12	27.46	+0.76	+0.68	+4.39	-0.09	-0.17	4.39
Average:	D65	22.6	164	332	3145	8	22.94	+0.67	+0.22	27.40	+0.77	+0.46	+4.46	+0.10	-0.21	4.47
10-1	C	14.4	490	164	3112	4	59.38	-0.12	+1.18	75.12	-5.73	+9.04	+15.74	-5.61	+7.86	18.47
10-2	C	14.2	490	164	3112	4	59.70	-0.30	+1.34	75.57	-5.83	+9.12	+15.87	-5.53	+7.78	18.52
Average:	C	14.3	490	164	3112	4	59.54	-0.21	+1.26	75.35	-5.78	+9.08	+15.81	-5.57	+7.82	18.50
10-1	D65	14.4	490	164	3112	4	59.49	-0.18	+1.13	74.47	-0.46	+5.43	+14.98	-0.28	+4.30	15.59
10-2	D65	14.2	490	164	3112	4	59.75	-0.32	+1.31	75.53	-0.71	+5.25	+15.78	-0.39	+3.94	16.27
Average:	D65	14.3	490	164	3112	4	59.62	-0.25	+1.22	75.00	-0.59	+5.34	+15.38	-0.34	+4.12	15.93

(Continued)

(Sheet 2 of 5)

Table 6 (Continued)

System No.-Panel No.	[1] Illum-inant	[2] Average Dry-film thickness (mils)	[6] Initial chalking (hours)	[6] 100% rusting in scribe lines (hours)	Total hours completed	[3] Chalk rating (completion)	[4]CIE 1976 CIELAB L* a* b* color data: Before exposure L*	Before exposure a*	Before exposure b*	After exposure L*	After exposure a*	After exposure b*	After exposure L*	After exposure a*	After exposure b*	After exposure E*ab
11-1	C	16.2	670	168	3135	4	63.82	-1.16	+1.55	72.43	-5.73	+6.68	+8.61	-4.57	+5.13	11.02
11-2	C	16.0	670	168	3135	4	63.75	-1.15	+1.45	71.51	-5.80	+6.74	+7.76	-4.65	+5.29	10.48
Average:	C	16.1	670	168	3135	4	63.79	-1.16	+1.50	71.97	-5.77	+6.71	+8.19	-4.61	+5.21	10.75
11-1	D65	16.2	670	168	3135	4	63.92	-1.24	+1.55	72.09	-0.80	+3.11	+8.17	+0.44	+1.56	8.33
11-2	D65	16.0	670	168	3135	4	63.80	-1.22	+1.45	71.01	-0.90	+2.76	+7.21	+0.32	+1.54	7.38
Average:	D65	16.1	670	168	3135	4	63.86	-1.23	+1.50	71.55	-0.85	+2.94	+7.69	+0.38	+1.55	7.85
12-1	C	20.2	168	168	3133	6	23.47	+0.64	+0.51	38.48	-3.22	+4.76	+15.01	-2.58	+4.25	15.81
12-2	C	23.1	168	503	3133	6	24.98	+0.47	+0.51	50.29	-4.02	+3.62	+25.30	-3.46	+3.11	25.72
Average:	C	21.7	168	336	3133	6	24.23	+0.56	+0.51	44.38	-3.62	+4.19	+20.16	-3.02	+3.68	20.71
12-1	D65	20.2	168	168	3133	6	23.76	+0.60	+0.55	37.99	-0.07	+2.44	+14.23	-0.67	+1.89	14.37
12-2	D65	23.1	168	503	3133	6	25.88	+0.53	+0.40	51.41	-0.52	+0.93	+25.52	-1.05	+0.53	25.55
Average:	D65	21.7	168	336	3133	6	24.83	+0.57	+0.48	44.70	-0.30	+1.69	+19.88	-0.86	+1.21	19.94
13-1	C	15.0	332	332	3123	4	92.05	-1.36	+3.70	88.50	-5.21	+11.96	-3.55	-3.85	+8.26	9.78
13-2	C	12.2	332	164	3123	4	91.96	-1.26	+3.24	88.54	-5.42	+12.25	-3.42	-4.16	+9.01	10.50
Average:	C	13.6	332	248	3123	4	92.01	-1.31	+3.47	88.52	-5.32	+12.11	-3.49	-4.01	+8.64	10.14
13-1	D65	15.0	332	332	3123	4	92.05	-1.37	+3.62	88.02	+0.69	+8.84	-4.03	+2.06	+5.22	6.91
13-2	D65	12.2	332	164	3123	4	92.07	-1.28	+3.20	88.57	+0.49	+7.77	-3.50	+1.77	+4.57	6.02
Average:	D65	13.6	332	248	3123	4	92.06	-1.33	+3.41	88.30	+0.59	+8.31	-3.77	+1.92	+4.90	6.47
14-1	C	7.0	652	167	3078	4	53.88	-0.26	-2.40	66.11	-5.34	+2.91	+12.23	-5.08	+5.31	14.27
14-2	C	7.0	652	167	3078	4	53.90	-0.31	-2.36	65.06	-5.25	+2.77	+11.16	-4.94	+5.13	13.24
Average:	C	7.0	652	167	3078	4	53.89	-0.29	-2.38	65.59	-5.30	+2.84	+11.70	-5.01	+5.22	13.76
14-1	D65	7.0	652	167	3078	4	54.20	-0.47	-2.41	65.04	-0.68	-0.61	+10.84	-0.21	+1.80	10.99
14-2	D65	7.0	652	167	3078	4	54.04	-0.47	-2.38	65.78	-0.73	-0.67	+11.74	-0.26	+1.71	11.87
Average:	D65	7.0	652	167	3078	4	54.12	-0.47	-2.40	65.41	-0.71	-0.64	+11.29	-0.24	+1.76	11.43
15-1	C	10.3	1161	334	3127	8	50.08	-0.37	-3.78	55.78	-5.07	-2.27	+5.70	-4.70	+1.51	7.54
15-2	C	10.8	1161	334	3127	8	50.39	-0.32	-4.09	55.19	-5.10	-2.18	+4.80	-4.78	+1.91	7.04
Average:	C	10.6	1161	334	3127	8	50.24	-0.35	-3.94	55.49	-5.09	-2.23	+5.25	-4.74	+1.71	7.28
15-1	D65	10.3	1161	334	3127	8	50.30	-0.45	-3.82	55.52	-1.11	-5.54	+5.22	-0.66	-1.72	5.54
15-2	D65	10.8	1161	334	3127	8	50.38	-0.50	-4.02	55.08	-1.17	-5.40	+4.70	-0.67	-1.38	4.94
Average:	D65	10.6	1161	334	3127	8	50.34	-0.48	-3.82	55.30	-1.14	-5.47	+4.96	-0.67	-1.55	5.24

(Continued)

(Sheet 3 of 5)

Table 6 (Continued)

System No.-Panel No.	[1] Illuminant	[2] Average Dry-film thickness (mils)	[6] Initial chalking (hours)	[6] 100% rusting in scribe lines (hours)	Total hours completed	[3] Chalk rating (completion)	[4] CIE 1976 CIELAB L* a* b* color data: Before exposure L*	a*	b*	After exposure L*	a*	b*	L*	a*	b*	E^*_{ab}
16-1	C	27.2	1155	828	3108	6	89.86	-1.05	+5.21	88.48	-0.44	+13.16	-1.38	+0.61	+7.95	8.09
16-2	C	26.2	1155	828	3108	6	88.67	-0.76	+3.40	87.46	-1.17	+13.01	-1.21	-0.41	+9.61	9.69
Average:	C	26.7	1155	828	3108	6	89.27	-0.91	+4.31	87.97	-0.81	+13.09	-1.30	+0.10	+8.78	8.87
16-1	D65	27.2	1155	828	3108	6	89.92	-1.02	+5.06	88.43	-6.42	+17.33	-1.49	-5.40	+12.27	13.49
16-2	D65	26.2	1155	828	3108	6	88.58	-0.73	+3.42	87.63	-7.10	+16.71	-0.95	-6.37	+13.29	14.77
Average:	D65	26.7	1155	828	3108	6	89.25	-0.88	+4.24	88.03	-6.76	+17.02	-1.22	-5.89	+12.78	14.12
17-1	C	26.6	1155	331	3108	6	84.81	-0.95	+2.37	85.68	-7.27	+14.51	+0.87	-6.32	+12.14	13.71
17-2	C	27.2	1155	3108	3108	6	90.10	-0.61	+5.85	88.17	-6.46	+17.72	-1.93	-5.85	+11.87	13.37
Average:	C	26.9	1155	1720	3108	6	87.46	-0.78	+4.11	86.93	-6.87	+16.12	-0.53	-6.09	+12.01	13.48
17-1	D65	26.6	1155	331	3108	6	86.15	-1.02	+2.71	86.56	-1.46	+10.93	+0.41	-0.44	+8.22	8.24
17-2	D65	27.2	1155	3108	3108	6	90.09	-0.47	+5.85	88.19	-0.48	+13.62	-1.90	-0.01	+7.77	8.00
Average:	D65	26.9	1155	1720	3108	6	88.12	-0.75	+4.28	87.38	-0.97	+12.28	-0.75	-0.23	+8.00	8.04
18-1	C	8.9	499	499	3115	6	95.60	-1.07	+1.39	89.35	-5.91	+13.07	-6.25	-4.84	+11.68	14.10
18-2	C	8.9	499	499	3115	6	95.48	-1.36	+2.38	89.68	-5.62	+13.81	-5.80	-4.26	+11.43	13.51
Average:	C	8.9	499	499	3115	6	95.54	-1.22	+1.89	89.52	-5.77	+13.44	-6.03	-4.55	+11.56	13.81
18-1	D65	8.9	499	499	3115	6	95.88	-1.13	+1.27	89.73	+0.07	+8.62	-6.15	+1.20	+7.35	9.66
18-2	D65	8.9	499	499	3115	6	95.74	-1.34	+2.30	89.70	+0.40	+9.52	-6.04	+1.74	+7.22	9.57
Average:	D65	8.9	499	499	3115	6	95.81	-1.24	+1.79	89.72	+0.24	+9.07	-6.10	+1.47	+7.29	9.62
19-1	C	9.5	1309	169	3115	6	76.36	-5.47	-7.46	79.26	-9.15	+5.93	+2.90	-3.68	+13.39	14.19
19-2	C	8.2	1309	332	3115	6	76.10	-5.43	-7.41	80.60	-8.98	+4.72	+4.50	-3.55	+12.13	13.42
Average	C	8.9	1309	251	3115	6	76.23	-5.45	-7.44	79.93	-9.07	+5.33	+3.70	-3.62	+12.76	13.77
19-1	D65	9.5	1309	169	3115	6	76.72	-5.86	-7.59	79.83	-3.77	+1.62	+3.11	+3.82	+4.61	6.75
19-2	D65	8.2	1309	332	3115	6	76.34	-5.85	-7.52	80.81	-3.60	+0.48	+4.47	+2.25	+3.17	5.92
Average:	D65	8.9	1309	251	3115	6	76.53	-5.86	-7.56	80.32	-3.69	+1.05	+3.79	+3.04	+3.89	6.22
20-1	C	40.2	2459	499	3115	4	75.47	-0.24	+19.95	60.70	-1.36	+12.53	-14.77	-1.12	-7.42	16.57
20-2	C	42.2	2459	499	3115	4	75.23	-0.20	+19.82	57.38	-0.59	+8.22	-17.85	-0.39	-11.60	21.29
Average:	C	41.2	2459	499	3115	4	75.35	-0.22	+19.89	59.04	-0.98	+10.38	-16.31	-0.76	-9.51	18.90
20-1	D65	40.2	2459	499	3115	4	75.34	+0.26	+20.43	62.62	+2.58	+8.18	-12.72	+2.32	-12.25	17.81
20-2	D65	42.2	2459	499	3115	4	75.90	+0.31	+19.75	58.98	+3.83	+5.50	-16.92	+3.52	-14.25	22.40
Average:	D65	41.2	2459	499	3115	4	75.62	+0.29	+20.09	60.80	+3.21	+6.84	-14.82	+2.92	-13.25	20.09

(Continued)

(Sheet 4 of 5)

Table 6 (Concluded)

System No.- Panel No.	[1] Illuminant	[2] Average Dry-film thickness (mils)	[6] Initial chalking (hours)	[6] 100% rusting in scribe lines (hours)	Total hours completed	[3] Chalk rating (completion)	[4]CIE 1976 CIELAB L* a* b* color data: Before exposure L*	Before exposure a*	Before exposure b*	After-exposure L*	After-exposure a*	After-exposure b*	After-exposure L*	After-exposure a*	After-exposure b*	E^*_ab
21-1	C	52.2	2459	499	3115	4	74.65	+0.09	+20.57	62.92	-1.71	+10.20	-11.73	-1.80	-10.37	15.76
21-2	C	54.1	2459	499	3115	4	74.77	+0.13	+19.64	59.41	-0.34	+9.27	-15.36	-0.47	-10.37	18.54
Average:	C	53.2	2459	499	3115	4	74.71	+0.11	+20.11	61.17	-1.03	+9.74	-13.55	-1.14	-10.37	17.10
21-1	D65	52.2	2459	499	3115	4	74.69	+0.57	+20.46	63.07	+2.75	+6.81	-11.62	+2.18	-13.65	18.06
21-2	D65	54.1	2459	499	3115	4	75.45	+0.61	+19.60	59.79	+3.93	+6.12	-15.66	+3.32	-13.48	20.93
Average:	D65	53.2	2459	499	3115	4	75.07	+0.59	+20.03	61.43	+3.34	+6.47	-13.64	+2.75	-13.57	19.44
22-1	C	8.1	2615	167	3078	6	38.47	+24.81	+16.46	51.64	0.00	+15.08	+13.17	-24.87	-1.38	28.18
22-2	C	8.3	2615	167	3078	6	38.63	+24.68	+16.27	55.06	+1.94	+7.71	+16.37	-22.74	-8.56	29.30
Average:	C	8.2	2615	167	3078	6	38.58	+24.75	+16.37	53.35	+0.97	+11.40	+14.77	-23.81	-4.97	28.46
22-1	D65	8.1	2615	167	3078	6	38.61	+25.83	+16.83	47.32	+3.71	+10.69	+8.71	-22.12	-6.14	24.55
22-2	D65	8.3	2615	167	3078	6	38.80	+25.31	+16.39	54.34	+6.40	+5.20	+15.54	-18.91	-11.19	26.91
Average:	D65	8.2	2615	167	3078	6	38.71	+25.57	+16.61	50.83	+5.06	+7.95	+12.13	-20.52	-8.67	25.36
23-1	C	27.6	1464	160	3083	6	67.46	-0.27	-0.81	79.89	-6.16	+4.17	+12.43	-5.89	+4.98	11.63
23-2	C	32.6	1464	160	3083	6	64.94	-0.29	-0.66	78.34	-6.07	+4.17	+13.40	-5.78	+4.83	15.37
Average:	C	30.1	1464	160	3083	6	66.20	-0.28	-0.74	79.12	-6.12	+4.17	+12.92	-5.84	+4.91	15.00
23-1	D65	27.6	1464	160	3083	6	67.50	-0.40	-0.85	79.97	-0.82	+0.05	+12.47	-0.42	+0.90	12.51
23-2	D65	32.6	1464	160	3083	6	64.80	-0.34	-0.70	78.34	-0.85	+0.11	+13.54	-0.51	+0.81	13.57
Average:	D65	30.1	1464	160	3083	6	66.15	-0.37	-0.78	79.16	-0.84	+0.08	+13.01	-0.47	+0.86	13.05
24-1	C	35.1	652	167	3078	8	56.19	-0.48	-0.69	63.38	-5.44	+5.22	+7.19	-4.96	+5.91	10.55
24-2	C	24.6	652	167	3078	8	56.30	-0.62	-0.26	63.94	-5.46	+4.70	+7.64	-4.84	+4.96	10.31
Average:	C	29.9	652	167	3078	8	56.25	-0.55	-0.48	63.66	-5.45	+4.96	+7.42	-4.90	+5.44	10.42
24-1	D65	35.1	652	167	3078	8	56.27	-0.53	-0.70	64.28	-0.98	+1.25	+8.01	-0.45	+1.95	8.26
24-2	D65	24.6	652	167	3078	8	56.50	-0.69	-0.24	63.99	-1.01	+1.16	+7.49	-0.32	+1.40	7.63
Average:	D65	29.9	652	167	3078	8	56.39	-0.61	-0.47	64.14	-1.00	+1.21	+7.75	-0.39	+1.68	7.94

Notes

1. The color data obtained from the Minolta CR-200b can be recorded for two Illuminants: C and D65. CIE Standard Illuminant C simulates a cloudy day and CIE Standard Illuminant D65 simulates a bright day. The color temperature of Illuminant D65 is lower than Illuminant C and the colors measure "cooler" when D65 is used. Illuminant C has been the most widely used standard illuminant since 1931. However, Illuminant D65 is coming into wider use. For this reason, and to provide a comparison of the colors under different illuminant conditions, CIE Standard Illuminant D65 is included in this table along with CIE Standard Illuminant C.

2. Initial chalking is the first appearance of definite chalking. Color fade, although an indication that chalking may be occurring, was not recorded as chalking.

3. Pictorial Standards of Coatings Defects and ASTM: D659-86. A rating of 2 is very heavy chalking and a rating of 10 is no chalking on the rating scale of 2, 4, 6, 8, and 10.

4. For an explanation of the CIE 1976 CIELAB L* a* b* Color Data System, consult Note No. 2 of Table No. 4.

5. For an explanation of the total color difference, ΔE^*_ab, consult Note No. 3 of Table No. 4.

6. The numbers of hours recorded are the numbers of hours of exposure as of the time the panels were examined. The exact numbers of hours by before initial chalking or 100 percent rusting in the scribe lines took place are unknown. However, in no instance would the numbers of hours be less than the recorded numbers of hours by more than 1 week's exposure time, approximately 164-168 hours.

(Sheet 5 of 5)

Table 7

Adhesion Test Data

System No. - Panel No. (Control [1] & 1)	Salt water immersion: [2] Average pull-off adhesion (lb/in^2)	Salt water immersion: Description of adhesive failure	Freshwater immersion: [2] Average pull-off adhesion (lb/in^2)	Freshwater immersion: Description of adhesive failure	QUV accelerated weathering test: [2] Average pull-off adhesion (lb/in^2)	QUV accelerated weathering test: Description of adhesive failure
1-Control (36.0 mils)	800	1 Dolly - 100% Intercoat 1 Dolly - 10% Intercoat, 90% glue line 1 Dolly - [4] NVT	800	See data under [3] SWI	800	See data under [3] SWI
1-1	595	1 Dolly - 50% Intercoat, 50% glue line 1 Dolly - 10% Intercoat, 90% glue line	-	[5] Continuing in test	608	1 Dolly - 20% Intercoat, 80% glue line 1 Dolly - 40% Intercoat, 60% glue line
1-2	620	1 Dolly - 30% Intercoat, 70% glue line 1 Dolly - 100% glue line	-	Continuing in test	615	1 Dolly - 100% glue line 1 Dolly - 10% Intercoat, 90% glue line
Average 1 and 2	658		-		611	
2-Control (32.7 mils)	592	1 Dolly - 30% Intercoat, 70% glue line 1 Dolly - 30% Intercoat, 70% glue line 1 Dolly - 100% glue line	592	See data under SWI	592	See data under SWI
2-1	670	1 Dolly - 30% Intercoat, 70% glue line 1 Dolly - 20% Intercoat, 80% glue line	-	Continuing in test	490	1 Dolly - 20% Intercoat, 80% glue line 1 Dolly - 20% Intercoat, 80% glue line
2-2	400	1 Dolly - 100% glue line 1 Dolly - 100% glue line	-	Continuing in test	300	1 Dolly - 80% Intercoat, 20% glue line 1 Dolly - 100% glue line
Average 1 and 2	535				395	
3-Control (17.7 mils)	180	1 Dolly - 100% Intercoat 1 Dolly - 90% Intercoat, 10% glue line 1 Dolly - NVT	180	See data under SWI	180	See data under SWI
3-1	140	1 Dolly - 100% substrate 1 Dolly - 100% substrate	-	Continuing in test	180	1 Dolly - 100% substrate 1 Dolly - 80% substrate, 20% glue line
3-2	200	1 Dolly - 30% Intercoat, 70% substrate 1 Dolly - NVT	-	Continuing in test	210	1 Dolly - 100% substrate, 70% substrate, 30% glue line
Average 1 and 2	170				195	
4-Control (39.6 mils)	403	1 Dolly - 100% substrate 1 Dolly - 100% substrate 10% substrate, 90% glue line	403	See data under SWI	403	See data under SWI
4-1	-	Continuing in test	-	Continuing in Test	305	1 Dolly - 30% Intracoat, 70% substrate 1 Dolly - 20% Intracoat, 80% substrate
4-2	-	Continuing in test	-	Continuing in test	290	1 Dolly - 3% Intracoat, 97% substrate 1 Dolly - 3% Intracoat, 97% substrate
Average 1 and 2	-				298	

(Continued)

(Sheet 1 of 7)

Table 7 (Continued)

System No. - Panel No. (Control [1] DFT)	Salt water immersion: [2] Average pull-off adhesion (lb/in^2)	Salt water immersion: Description of adhesive failure	Freshwater immersion: [2] Average pull-off adhesion (lb/in^2)	Freshwater immersion: Description of adhesive failure	QUV accelerated weathering test: [2] Average pull-off adhesion (lb/in^2)	QUV accelerated weathering test: Description of adhesive failure
5-Control (40.4 mils)	300	1 Dolly - 20% intercoat, 80% glue line 1 Dolly - 10% intercoat, 90% glue line 1 Dolly - 20% intercoat, 80% glue line	300	See data under SWI	300	See data under SWI
5-1	175	1 Dolly - 5% intercoat, 95% substrate 1 Dolly - 5% intercoat, 95% substrate	145	1 Dolly - 75% intercoat, 25% substrate 1 Dolly - 70% intercoat, 30% substrate	340	1 Dolly - 10% intercoat, 90% glue line 1 Dolly - 10% intercoat, 90% glue line
5-2	100	1 Dolly - 100% substrate 1 Dolly - 75% intercoat, 25% substrate	163	1 Dolly - 80% intercoat, 20% substrate 1 Dolly - 20% intercoat, 80% substrate	370	1 Dolly - 100% glue line 1 Dolly - 20% intercoat, 80% glue line
Average 1 and 2	138		154		355	
6-Control (42.7 mils)	300	1 Dolly - 20% intercoat, 80% glue line 1 Dolly - 10% intercoat, 90% glue line 1 Dolly - 40% intercoat, 10% substrate 50% glue line	300	See data under SWI	300	See data under SWI
6-1	245	1 Dolly - 40% substrate, 60% glue line 1 Dolly - 60% substrate, 40% glue line	150	1 Dolly - 10% intercoat, 90% substrate 1 Dolly - 10% intercoat, 90% substrate	525	1 Dolly - 10% intercoat, 90% glue line 1 Dolly - 40% intercoat, 60% glue line
6-2	350	1 Dolly - 100% glue line 1 Dolly - 50% intercoat, 50% substrate	125	1 Dolly - 100% substrate 1 Dolly -NVT	400	1 Dolly - 10% intercoat, 90% glue line 1 Dolly - 90% intercoat, 10% glue line
Average 1 and 2	290		138		463	
7-Control (10.5 mils)	197	1 Dolly - 80% intercoat, 20% substrate 1 Dolly - 50% intercoat, 50% substrate 1 Dolly - 98% intercoat, 2% substrate	197	See data under SWI	197	See data under SWI
7-1	200	1 Dolly - 60% intercoat, 35% substrate 5% glue line 1 Dolly - NVT	-	Continuing in test	108	1 Dolly - 50% intercoat, 50% glue line 1 Dolly - 40% intercoat, 60% substrate
7-2	195	1 Dolly - 60% intercoat, 40% glue line 1 Dolly - 70% intercoat, 30% substrate	-	Continuing in test	95	1 Dolly - 50% intercoat, 50% glue line 1 Dolly - 94% intercoat, 6% glue line
Average 1 and 2	198		-		102	

(Continued)

Table 7 (Continued)

System No. - Panel No. (Control [1] DFT)	Salt water immersion		Freshwater immersion		QUV accelerated weathering test	
	[2] Average pull-off adhesion (lb/in^2)	Description of adhesive failure	[2] Average pull-off adhesion (lb/in^2)	Description of adhesive failure	[2] Average pull-off adhesion (lb/in^2)	Description of adhesive failure
8-Control (14.7 mils)	190	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat 1 Dolly - NVT	190	See data under SWI	190	See data under SWI
8-1	-	Continuing in test	-	Continuing in test	-	1 Dolly - NVT 1 Dolly - NVT
8-2	-	Continuing in test	-	Continuing ` test	90	1 Dolly - 100% intercoat
Average 1 and 2	-		-		90	
9-Control (21.0 mils)	363	1 Dolly - 100% intercoat 1 Dolly - 80% intercoat, 20% substrate 1 Dolly - 96% intercoat, 4% substrate	363	See data under SWI	363	See data under SWI
9-1	-	Continuing in test	-	Continuing in test	340	1 Dolly - 80% intercoat, 20% glue line 1 Dolly - '00% intercoat
9-2	-	Continuing in test	-	Continuing in test	290	1 Dolly - 80% intercoat, 20% substrate 1 Dolly - 100% intercoat
Average 1 and 2	-		-		315	
10-Control (15.0 mils)	93	1 Dolly - 100% substrate 1 Dolly - 80% intercoat, 20% glue line 1 Dolly - 20% intercoat, 80% subs rate	93	See data under SWI	93	See data under SWI
10-1	213	1 Dolly - 80% substrate, 20% glue line 1 Dolly - 95% substrate, 5% glue line	-	Continuing in test	190	1 Dolly - 100% substrate 1 Dolly - NVT
10-2	115	1 Dolly - 80% substrate, 20% glue line 1 Dolly - 100% substrate	-	Continuing in test	140	1 Dolly - 20% intercoat, 80% substrate 1 Dolly - 60% substrate, 40% glue line
Average 1 and 2	164				165	
11-Control (15.4 mils)	268	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat 1 Dolly - 100% intercoat	268	See data under SWI	268	See data under SWI
11-1	145	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat	-	Continuing in test	130	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat
11-2	163	1 Dolly - 90% intercoat, 10% substrate 1 Dolly - 100% intercoat	-	Continuing in test	155	1 Dolly - 50% intercoat, 50% substrate 1 Dolly - 100% intercoat
Average 1 and 2	154				143	

(Continued)

(Sheet 3 of 7)

Table 7 (Continued)

System No. - Panel No. (Control [1] DFT)	Salt water immersion: [2] Average pull-off adhesion (lb/in^2)	Salt water immersion: Description of adhesive failure	Freshwater immersion: [2] Average pull-off adhesion (lb/in^2)	Freshwater immersion: Description of adhesive failure	QUV accelerated weathering test: [2] Average pull-off adhesion (lb/in^2)	QUV accelerated weathering test: Description of adhesive failure
12-Control (16.8 mils)	308	1 Dolly - 100% Intracoat 1 Dolly - 100% Intracoat 1 Dolly - 100% Intracoat	308	See data under SWI	308	See data under SWI
12-1	175	1 Dolly - 50% Intracoat, 50% substrate 1 Dolly - 50% Intracoat, 50% substrate	-	Continuing in test	175	1 Dolly - 90% Intracoat, 10% glue line 1 Dolly - 45% Intracoat, 55% glue line
12-2	235	1 Dolly - 25% Intracoat, 75% substrate 1 Dolly - 25% Intracoat, 75% substrate	-	Continuing in test	195	1 Dolly - 100% Intracoat 1 Dolly - 90% Intracoat, 10% glue line
Average 1 and 2	205				185	
13-Control (10.3 mils)	97	1 Dolly - 100% Intercoat 1 Dolly - 100% Intercoat 1 Dolly - 100% substrate	97	See data under SWI	97	See data under SWI
13-1	140	1 Dolly - 50% Intercoat, 50% substrate 1 Dolly - 70% substrate, 30% glue line	-	Continuing in test	105	1 Dolly - 100% Intercoat 1 Dolly - 10% Intercoat, 90% substrate
13-2	150	1 Dolly - 75% Intercoat, 25% substrate 1 Dolly - 100% substrate	-	Continuing in test	100	1 Dolly - 100% Intercoat 1 Dolly - 100% substrate
Average 1 and 2	145				103	
14-Control (6.5 mils)	327	1 Dolly - 100% Intracoat 1 Dolly - 100% Intracoat 1 Dolly - 100% Intracoat	327	See data under SWI	327	See data under SWI
14-1	195	1 Dolly - 80% Intracoat, 20% substrate 1 Dolly - 80% Intracoat, 20% substrate	205	1 Dolly - 10% Intracoat, 90% substrate 1 Dolly - 10% Intracoat, 90% substrate	-	1 Dolly - NVT 1 Dolly - NVT
14-2	290	1 Dolly - 80% Intracoat, 20% substrate 1 Dolly - NVT	195	1 Dolly - 10% Intracoat, 90% substrate 1 Dolly - 10% Intracoat, 90% substance	65	1 Dolly - 100% substrate 1 Dolly - 100% substrate
Average 1 and 2	243		200		65	
15-Control (10.5 mils)	250	1 Dolly - 100% Intercoat 1 Dolly - 100% Intercoat 1 Dolly - 100% Intercoat	250	See data under SWI	250	See data under SWI
15-1	245	1 Dolly - 90% Intercoat, 10% glue line 1 Dolly - 50% Intercoat, 50% substrate	-	Continuing in test	245	1 Dolly - 100% Intercoat 1 Dolly - 80% Intercoat, 20% substrate
15-2	-	1 Dolly - NVT 1 Dolly - NVT	-	Continuing in test	250	1 Dolly - 90% Intercoat, 10% substrate 1 Dolly - 30% Intercoat, 70% glue line
Average 1 and 2	245				248	

(Continued)

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Table 7 (Continued)

System No. - Panel No. (Control [1] DFT)	Salt water immersion: [2] Average pull-off adhesion (lb/in^2)	Salt water immersion: Description of adhesive failure	Freshwater immersion: [2] Average pull-off adhesion (lb/in^2)	Freshwater immersion: Description of adhesive failure	QUV accelerated weathering test: [2] Average pull-off adhesion (lb/in^2)	QUV accelerated weathering test: Description of adhesive failure
16-Control (25.5 mils)	313	1 Dolly - 80% substrate, 20% glue line 1 Dolly - 80% substrate, 20% glue line 1 Dolly - 20% intercoat, 80% substrate	313	See data under SWI	313	See data under SWI
16-1	-	Continuing in test	-	Continuing in test	120	1 Dolly - 80% substrate, 20% glue line 1 Dolly - 40% substrate, 60% glue line
16-2	-	Continuing in test	-	Continuing in test	125	1 Dolly - 80% substrate, 20% glue line 1 Dolly - 80% substrate, 20% glue line
Average 1 and 2	-		-		123	
17-Control (31.6 mils)	333	1 Dolly - 80% substrate, 20% glue line 1 Dolly - 80% substrate, 20% glue line 1 Dolly - 5 % intercoat, 95% substrate	333	See data under SWI	333	See data under SWI
17-1	-	Continuing in test	-	Continuing in test	175	1 Dolly - 80% substrate, 20% glue line 1 Dolly - 90% substrate, 10% glue line
17-2	-	Continuing in test	-	Continuing in test	150	1 Dolly - 80% substrate, 20% glue line 1 Dolly - 80% substrate, 20% glue line
Average 1 and 2	-				163	
18-Control (8.8 mils)	163	1 Dolly - 100% intercoat 1 Dolly - 80% intercoat, 20% glue line 1 Dolly - 80% intercoat, 20% glue line	163	See data under SWI	163	See data under SWI
18-1	205	1 Dolly - 80% intercoat, 20% glue line 1 Dolly - 20% intercoat, 80% glue line	-	Continuing ion test	113	1 Dolly - 70% intercoat, 30% glue line 1 Dolly - 90% intercoat, 10% glue line
18-2	100	1 Dolly - 70% intercoat, 30% glue line 1 Dolly - NVT	-	Continuing in test	125	1 Dolly - 80% intercoat, 20% glue line 1 Dolly - NVT
Average 1 and 2	153		-		119	
19-Control (8.6 mils)	233	1 Dolly - 40% intercoat, 60% glue line 1 Dolly - 90% intercoat, 10% glue line 1 Dolly - 60% intercoat, 40% glue line	233	See data under SWI	233	See data under SWI
19-1	188	1 Dolly - 70% intercoat, 30% glue line 1 Dolly - 10% intercoat, 90% glue line	-	Continuing in test	100	1 Dolly - 20% intercoat, 80% glue line 1 Dolly - 50% intercoat, 50% glue line
19-2	75	1 Dolly - 10% intercoat, 90% glue line 1 Dolly - 100% glue line	-	Continuing in test	95	1 Dolly - 50% intercoat, 50% glue line 1 Dolly - 100% intercoat
Average 1 and 2	132		-		285	

(Continued)

(Sheet 5 of 7)

Table 7 (Continued)

System No. - Panel No. (Control [1] DFT)	Salt water immersion: [2] Average pull-off adhesion (lb/in^2)	Salt water immersion: Description of adhesive failure	Freshwater immersion: [2] Average pull-off adhesion (lb/in^2)	Freshwater immersion: Description of adhesive failure	QUV accelerated weathering test: [2] Average pull-off adhesion (lb/in^2)	QUV accelerated weathering test: Description of adhesive failure
20-Control (47.0 mils)	285	1 Dolly 100% intercoat 1 Dolly - 100% intercoat 1 - NVT	285	See data under SWI	285	See data under SWI
20-1	-	Continuing in test	-	Continuing in test	130	1 Dolly - 100% intercoat 1 Dolly - 90% intercoat, 10% glue line
20-2	-	Continuing in test	-	Continuing in test	-	1 Dolly - NVT 1 Dolly - NVT
Average 1 and 2	-				130	
21-Control (54.0 mils)	330	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat 1 Dolly - 100% intercoat	330	See data under SWI	330	See data under SWI
21-1	-	Continuing in test	-	Continuing in test	200	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat
21-2	-	Continuing in test	-	Continuing in test	225	1 Dolly - 100% intercoat 1 Dolly - 100% glue line
Average 1 and 2	-		-		213	
22-Control (5.2 mils)	200	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat 1 Dolly - NVT	200	See data under SWI	200	See data under SWI
22-1	-	1 Dolly - NVT 1 Dolly - NVT	225	1 Dolly - 10% intercoat, 90% substrate 1 Dolly - 100% substrate	90	1 Dolly - 100% intercoat 1 Dolly - NVT
22-2	170	1 Dolly - 10% intercoat, 90% substrate 1 Dolly - 100% substrate	188	1 Dolly - 10% intercoat, 90% substrate 1 Dolly - 100% substrate	120	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat
Average 1 and 2	170		207		105	
23-Control (57.8 mils)	427	1 Dolly - 30% intercoat, 70% glue line 1 Dolly - 20% intercoat, 70% glue line 1 Dolly - 100% intercoat	427	See data under SWI	427	See data under SWI
23-1	245	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat	-	Continuing in test	600	1 Dolly - 40% intercoat, 60% glue line 1 Dolly - 40% intercoat, 60% glue line
23-2	240	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat	-	Continuing in test	650	1 Dolly - 40% intercoat, 60% glue line 1 Dolly - 100% glue line
Average 1 and 2	243		-		625	

(Continued)

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Table 7 (Concluded)

System No. - Panel No. (Control [1] DFT)	Salt water immersion		Freshwater immersion		QUV accelerated weathering test	
	[2] Average pull-off adhesion (lb/in^2)	Description of adhesive failure	[2] Average pull-off adhesion (lb/in^2)	Description of adhesive failure	[2] Average pull-off adhesion (lb/in^2)	Description of adhesive failure
24-Control (34.8 mils)	483	1 Dolly - 100% intercoat 1 Dolly - 60% intercoat, 40% glue line 1 Dolly - 50% intercoat, 50% glue line	483	See data under SWI	483	See data under SWI
24-1	505	1 Dolly - 60% intercoat, 40% glue line 1 Dolly - 100% intercoat	-	Continuing in tst	525	1 Dolly - 30% intercoat, 70% glue line 1 Dolly - 100% intercoat
24-2	450	1 Dolly - 100% intercoat 1 Dolly - 100% intercoat	-	Continuing in test	495	1 Dolly - 30% intercoat, 70% glue line 1 Dolly - 100% intercoat
Average 1 and 2	478		-		510	

Notes

1. DFT = Dry-film Thickness. The DFT of the immersed and exposed panels appear in Tables No. 3, 4, and 5.

2. ASTM: D4541-85. An Elcometer adhesion tester was used. The dollies were isolated by cutting around the base of the dollies to the substrate.

3. SWI = Saltwater Immersion

4. NVT = Not Valid Test

5. Because pull-off adhesion is a destructive test, only those panels which were removed from the immersion tests because of blistering were tested for adhesion. The QUV Accelerated Weathering Test was run for a finite period of time (approximately 3000 hours). Consequently, all of the exposed panels were tested for adhesion.

Table 8

Mandrel Bend Test Data

System No. (one panel tested)	Average dry-film thickness (mils)	Description of convex immediate bending area	System No. (one panel tested)	Average dry-film thickness (mils)	Description of convex immediate bending area	System No. (one panel tested)	Average dry-film thickness (mils)	Description of convex immediate bending area
1	35.0	No cracking, no loss of adhesion.	9	21.5	Cracking through to substrate, no loss of adhesion.	17	30.5	Cracking through to substrate, no loss of adhesion.
2	27.1	No cracking, no loss of adhesion.	10	16.0	Cracking through to substrate, no loss of adhesion.	18	8.8	Hairline cracking of topcoat, very slight cracking in intermediate coat, no loss of adhesion.
3	19.5	Cracking and some loss of adhesion on top sides of bending area. Adhesion good right on top of bending area.	11	14.6	Cracking through tc substrate, no loss of adhesion.	19	8.8	Slight cracking of topcoat, no loss of adhesion.
4	71.4	No cracking, no loss of adhesion.	12	17.1	Cracking through tc substrate, no loss of adhesion.	20	46.9	Cracking at top of bend to primer, 1/2-inch long. Loss of adhesion on each side of crack.
5	40.2	No cracking, no loss of adhesion.	13	11.2	Cracking through to substrate, no loss of adhesion.	21	53.8	Cracking at two parallel areas at top of bending area to primer, small 1/2-inch strip between cracks partially disbonded.
6	42.9	Cracking of white topcoat. No cracking observed on lower coats. No loss of adhesion.	14	6.5	No cracking, no loss of adhesion.	22	5.1	No cracking, no loss of adhesion.
7	11.1	No cracking, no loss of adhesion.	15	10.4	No cracking, no loss of adhesion.	23	59.1	No cracking, no loss of adhesion.
8	14.7	Cracking at center of top bending area through to substrate. Some loss of adhesion.	16	27.6	Cracking through to substrate, no loss of adhesion.	24	23.5	No cracking, no loss of adhesion.

PART IV: DISCUSSION

Coating System Performance

37. Systems 1 and 23, and 2 and 24, are grouped together since the main difference between these common systems is the technique of primer application. The same primer was used with all four systems. Systems 1 and 23 are the same elastomeric 100-percent solids aromatic polyurethane product from the same manufacturer. The same manufacturer also produced Systems 2 and 24, which are the same 70-percent ' ıme solids elastomeric aromatic-aliphatic polyurethane product. All four coating systems are thick film (30 to 32 mils). The difference between Systems 1 and 2 and 23 and 24 is in the method used to measure the dry film thickness of the primer. Systems 1 and 2 had the primer dry film thickness measured from the valleys of the blasting profile, although care was taken to coat the peaks. The profile was still showing after priming. Systems 23 and 24 had the dry film thickness of the primer measured in the conventional way, above the peaks.

38. When Systems 1 and 23 are compared, it can be seen that System 1 had higher values in the Elcometer pulloff adhesion test on the control and SW immersion panels and approximately the same value on the QUV accelerated weathering test. The control panel of System 1 was the only one in the investigation that had one reading over 1000 lb/sq in. (considered as 1000 lb/sq in. for averaging). Also, the time required before initial blistering in the SW test was a medium 1001 hours for System 1, versus a low 486 hours for System 23. For the Elcometer pulloff adhesion test, the average values (SW immersion) were 658 lb/sq in. and 243 lb/sq in., respectively. These results indicate that the manufacturer's recommended method of priming (i.e., with the blasting profile still visible after priming) has merit.

39. Systems 2 and 24, the 70-percent volume solids aromatic-aliphatic polyurethane materials, did not show as great a difference in performance between the two methods of priming. However, the customary method of film thickness calculation (over the peaks of the profile) showed some advantages in pulloff adhesion across the board, and the time to initial blistering in the SW immersion test was longer. When they were removed from the SW immersion test, all four systems were free of blisters on the backs of the panels. The systems did not show any blistering in FW.

40. All four systems were in the light-to-medium chalking range in the QUV accelerated weathering test, with chalk ratings of 6 to 8. As expected, the aromatic-aliphatic polyurethane systems had smaller magnitudes of total color difference (8.20 to 10.42 versus 15.00 to 29.34) after exposure in the QUV. All four systems exhibited no cracking or loss of adhesion in the 1-in. mandrel bend test. Either method of priming would appear to be satisfactory with Systems 2 and 24. All four systems also have medium waiting periods (4

days at 75° F) after the last coat has been applied before immersion. Dry film thickness for the four systems is 32 mils. (All dry film thicknesses used in calculations and tables are the manufacturers' target thicknesses.)

41. System 3 is an 80-percent volume solids, self-priming, medium dry film thickness (16 mils) epoxy-amine system. Although it blistered at 1001 hours in the SW immersion test (the backs of the panels were blister-free), it was blister-free in the FW immersion test after 5745 hours of immersion. Although pulloff adhesion values were relatively low, adhesion of this system has proved adequate in field situations, and there was negligible change in the values after SW immersion and QUV exposure. Total color difference values after immersion were the lowest for any system tested (2.21 SW, 2.35 FW). However, total color difference after QUV exposure was substantial (22.42), although the chalk rating (8) was light to moderate. Cracking and some loss of adhesion were noted in the 1-in. mandrel bend test. The waiting period before immersion at an ambient temperature of 75° F after the final coat has been applied is only 3 days. Where appearance is important in nonimmersed areas, a weathering topcoat, such as an aliphatic polyurethane, would be necessary.

42. System 4 is a 100-percent solids, high dry film thickness (50 mils), one-coat aromatic polyurethane system requiring heated, plural-component spraying application equipment. Performance in both the SW and FW immersion tests was good, with no blistering on the panels after 5574 hours. Pulloff adhesion values were relatively good for the control (403 lb/sq in.) and the QUV exposed (298 lb/sq in.) panels. Total color difference was moderate and uniform at the 11.35 to 11.68 level after both immersion and QUV testing. Chalking was surprisingly light with a rating of 9, the second best rating of all the coating systems tested. No cracking or loss of adhesion was reported for the 1-in. mandrel bend test. The waiting period before immersion at an ambient temperature of 75° F is only 3 days.

43. Systems 5 and 6 are 70-percent volume solids elastomeric aromatic polyurethanes, aromatic diamine cured. Panels coated with System 6 were given a topcoat of 80-percent volume solids aliphatic polyurethane. The same low volume solids primer is used with both systems. Both systems feature high film thicknesses, 35 to 36 mils for System 5, and 37 to 39 mils for System 6. These coating systems had the third and fourth longest periods before initial blistering in SW immersion; 1494 hours (No. 5) and 1990 hours (No. 6). For FW immersion, it took 2725 (No. 5) and 2559 (No. 6) hours before initial blistering. No blistering was observed on the backs of the SW immersion panels when they were removed from testing at 3135 hours. There were, however, some blisters on the backs of System 5 panels and on the back of one panel of System 6 after the same number of hours in FW immersion. Control pulloff adhesion values were 300 lb/sq in. for both coating systems and remained at an adequate level after immersion and QUV exposure. System 5 had a medium chalk

rating of 6, but System 6 had the highest (best) chalk rating of all the coating systems at a rating of 10. System 5 has one of the shortest times to immersion after the final coat has been applied when the ambient temperature is 75° F; 1 day. System 6 requires 4 days before immersion under the same ambient conditions. Neither system exhibited loss of adhesion in the 1-in. mandrel bend test, although System 6 had some cracking of the topcoat. System 5 exhibited no cracking. Total color difference after immersion and QUV exposure was low to moderate for both systems with values of 2.65 to 13.38.

44. Systems 7 and 8 have 61-percent volume solids epoxy-cycloaliphatic polyamine topcoats, with 71-percent volume solids epoxy-polyamide primers. System 8 has a low-solids anticorrosive (zinc chromate) primer added with the epoxy-polyamide primer as an intermediate coat. These systems have low to medium (9 mils) dry film thicknesses. System 8 was included in the investigation to test the theory that zinc chromate is deleterious to immersion primers. Because zinc chromate may have the potential to damage the environment, System 8 should not be field tested. However, its good performance in the immersion tests makes this system one well worth some development work to replace the zinc chromate with an environmentally acceptable anticorrosive pigment with equal performance. System 8 will be continued in both the SW and FW immersion tests, since no blistering has been observed in either test after 4749 hours. It would seem that the type of zinc chromate used and the overall formulation have a greater effect on immersion resistance than the presence of zinc chromate, as such.

45. System 7, the one of greater immediate interest, also did relatively well in the immersion tests. It had one of the longest average periods in SW immersion before initial blistering (2639 hours). One panel completed 4283 hours in the SW immersion test before blistering (there was also some blistering on the back), but the average was pulled down by the second panel which had initial blistering at 994 hours, although there was no blistering on the back. The panels in the FW immersion test are blister-free after 4749 hours of immersion. Pulloff adhesion values after QUV exposure and SW immersion were moderate, in the range of 102 to 198 lb/sq in., with the control value being 197 lb/sq in. Chalk rating in the QUV accelerated weathering test was 6, which is medium chalking. Total color difference was medium (9.41 to 11.93) after immersion and QUV exposure. There was no cracking or loss of adhesion on the 1-in. mandrel bend test. Time to immersion following the application of the final coat when the ambient temperature is 75 °F is a medium 4 days. Its application properties are similar to those of a conventional epoxy coating. In partial immersion conditions, a weathering topcoat, such as an aliphatic polyurethane, would be desirable where appearance was important.

46. System 9 is a self-priming, 100-percent solids, epoxy-polyamine with a medium-high dry film thickness of 20 mils. Although this coating system was applied in the same conventional manner as the other coating

systems, it can also be applied under water. Application requires special, but not very unusual, equipment. The system completed 5574 hours in both the SW and FW immersion tests without blistering. Its pulloff adhesion value on the control panel was 363 lb/sq in. There was no cracking or loss of adhesion on the 1-in. mandrel bend test. Total color difference after immersion and QUV exposure was relatively small (3.54 to 4.57). Chalking was light, with a chalk rating of 8. System 9 can be placed in immersion service 1 day after the final coat has been applied when the ambient temperature is 75° F. This coating system is the only one in the investigation that allows repair of the immersed coating without dewatering.

47. System 10 is a 75-percent volume solids cycloaliphatic amine cured epoxy with a 77-percent volume solids primer of the same generic composition. Total dry film thickness is a low-to-medium 9 to 13 mils. Of those coating systems that blistered during the initial 3000-hour immersion period in SW, System 10 had the highest average time to initial blistering of 2863 hours. Performance in the FW immersion test, in which it is being continued, was satisfactory with no blistering at a total immersion time of 3242 hours. There were no blisters on the backs of the panels in either the SW or FW immersion tests. Pulloff adhesion values were 93 lb/sq in. for the control although they increased to 164 lb/sq in. after SW immersion and 165 lb/sq in. after QUV exposure. With a chalk rating of 4, it exhibited heavy chalking in QUV exposure. Total color difference for the immersion and QUV exposure tests was medium-to-high with values of 6.64 to 18.50. It exhibited cracking, but no loss of adhesion, in the 1-in. mandrel bend test. The time required before immersion after the last coat has been applied when the ambient temperature is 75° F is 5 days. Of all the coating systems tested, it was the one most nearly like a conventional epoxy in handling and application properties. A weathering topcoat, such as an aliphatic polyurethane, would be desirable where appearance was important in partial immersion applications.

48. System 11 is a self-priming, 83-percent volume solids, epoxy-polyamide with a medium dry film thickness of 16 mils. Time to initial blistering in the SW immersion test was 670 hours and, at removal, there were blisters on the backs of the panels. It is unblistered in the FW immersion test after 5077 hours. Pulloff adhesion values were 268 lb/sq in. for the control panel versus 154 lb/sq in. after SW immersion and 143 lb/sq in. after QUV exposure. Chalking after QUV exposure was heavy, the chalk rating being 4. Total color difference was medium with values of 10.75 to 13.44 for the QUV exposure and immersion tests. It exhibited cracking, but no loss of adhesion, in the 1-in. mandrel bend test. The time required before immersion after the last coat has been applied when the ambient temperature is 75 °F is medium-to-long (7 days). In partial immersion conditions, a weathering topcoat such as an aliphatic polyurethane, would be desirable where appearance was important.

49. System 12 is a self-priming, 100-percent solids, coal-tar epoxy that is applied in one coat to a medium-high, dry film thickness of 20 mils. Heated, plural-component spraying equipment is required for application. In the SW immersion test, initial blistering occurred at 1169 hours, with blistering also on the backs of the panels. There was no blistering in the FW immersion test after 5403 hours of immersion. Pulloff adhesion values were satisfactory at 308 lb/sq in. for the control panel, 205 lb/sq in. after SW immersion, and 185 lb/sq in. after QUV exposure. Total color difference was relatively low after the immersion tests (6.03 and 4.01), but relatively high after QUV exposure (20.71). Chalking was medium after QUV exposure, a chalk rating of 6. There was cracking, but no loss of adhesion, in the 1-in. mandrel bend test. The time required before immersion when the ambient temperature is 75° F is short (3 days). Direct sunlight tends to degrade coal-tar and most other bituminous materials. The application of two coats of a compatible epoxy aluminum coating would be desirable to protect System 12 if exposure to direct sunlight is likely to be encountered. Aluminum coatings are preferable for application over coal-tar coating systems because coal-tar systems tend to "bleed," and the "platey" structure of epoxy aluminum coatings have proven in the field that they are an acceptable topcoat for coal-tar epoxies.

50. System 13 is a self-priming, 66-percent volume solids epoxy-polyamide with a low-to-medium dry film thickness of 12 mils. The time to initial blistering in SW was 829 hours with no blistering on the backs of the panels. It remains unblistered in FW after 4407 hours of immersion. Pulloff adhesion was 97 lb/sq in. for the control, 145 lb/sq in. after SW immersion, and 103 lb/sq in. after QUV exposure. Chalking after QUV exposure was relatively heavy, with a chalk rating of 4. Total color difference for the immersion and QUV tests was moderate-to-heavy with values from 10.14 to 27.35. There was some cracking, but no loss of adhesion, in the 1-in. mandrel bend test. When the ambient temperature is 75° F, the minimum time before immersion following application of the final coat is only 2 days. Where appearance is important in partial immersion, a compatible weathering topcoat, such as an aliphatic polyurethane coating, would be desirable.

51. Systems 14 and 22 will be discussed together, since both are waterborne acrylic modified vinyl coatings produced by the same manufacturer. At 8 and 6 mils dry film thickness, respectively, they were the thinnest coatings investigated. Recoating problems have been evidenced by System 14 and, to a lesser extent, by System 22. System 14 was originally planned as a two-coat system, but problems with intercoat adhesion dictated a cutback to a one-coat system. Both coating systems blistered early in both the SW and FW immersion tests and blistered on the backs, as well as the scribed sides, of the panels. In the pulloff adhesion test, System 14 recorded a value of 327 lb/sq in. (control), and System 22 recorded a value of 200 lb/sq in. (control).

Unidentified bacterial or microbial growth was observed on the QUV accelerated weathering panels. Neither system evidenced any cracking or loss of adhesion in the 1-in. mandrel test. Both coating systems require 7 days (medium-to-long) before immersion after the final coat has been applied when the ambient temperature is 75° F.

52. System 15 is a solventborne vinyl coating system (VR-6) with a low-to-medium dry film thickness of 10 mils. It was in the SW immersion test 994 hours before initial blistering was recorded. Blisters were observed on the back of one panel. No blisters have been observed on the FW immersion panels after 4749 hours of immersion. Pulloff adhesion values for the control, SW immersed, and QUV exposed panels were almost constant at 250 lb/sq in., 245 lb/sq in., and 248 lb/sq in., respectively. Total color difference for the immersion and QUV tests was medium with values of 7.28 to 11.62. There was no cracking or loss of adhesion in the 1-in. mandrel bend test. Chalking was light, the chalk value being 8. A long period (10 days) is required before immersion after the final coat has been applied when the ambient temperature is 75° F.

53. Systems 16 and 17 are 100-percent solids highly modified styrene polyesters. The systems differ in that the intermediate coat of System 17 contains a silica-type filler. Both systems are unblistered in both the SW and FW immersion tests after 3906 hours. Dry film thicknesses of these coating systems are relatively heavy at 26 to 34 mils. Pulloff adhesion values were 313 lb/sq in. and 333 lb/sq in., respectively, for the controls and 123 lb/sq in. and 163 lb/sq in., respectively, after QUV exposure. Both systems had a chalk rating of 6 (medium). Total color difference for the immersion and QUV tests was medium-to-large with values ranging from 8.87 to 19.04. Both coating systems had cracking, but no loss of adhesion, in the 1-in. mandrel bend test. The time required before immersion after the final coat has been applied when the ambient temperature is 75° F is only 2 hours, the shortest time required for any coating system in the investigation. In partial immersion service, where appearance was important, a compatible weathering topcoat recommended by the manufacturer would be desirable.

54. System 18 is MIL-P-24441, formulas No. 150, 151, and 152, type I, epoxy-polyamide. This coating system is, like VR-6, well known and widely used. It consists of a primer, intermediate coat, and topcoat, all of which are 60-percent volume solids. Total dry film thickness for this coating system is a relatively low 6 to 9 mils. Initial blistering in SW immersion took place at 499 hours. There was no blistering on the backs of the panels. No blistering has occurred after 3582 hours in the FW immersion test. Pulloff adhesion values were: control, 163 lb/sq in.; after SW immersion, 153 lb/sq in.; and after QUV exposure, 119 lb/sq in. Chalking was medium with a chalk rating of 6. Total color difference for the immersion and QUV tests was medium-to-large with a range of 13.81 to 36.17. There was cracking, but no

loss of adhesion, in the 1-in. mandrel bend test. The time required before immersion after the last coat has been applied when the ambient temperature is 75° F is a medium-to-long 7 days. In partial immersion, a compatible weathering topcoat would be advisable if appearance is important.

55. System 19 is based on MIL-P-24441, type I. It is, however, a two-coat system with 65-percent volume solids. Total dry film thickness is a low-to-medium 8 to 10 mils. Initial blistering in SW immersion was recorded at 332 hours. There was no blistering on the backs of the panels. No blistering has occurred after 3582 hours of FW immersion. Pulloff adhesion values were: control, 233 lb/sq in.; after SW immersion, 132 lb/sq in.; and after QUV exposure, 98 lb/sq in. Chalking was medium, with a chalk rating of 6. Total color difference for the immersion and QUV tests was medium-to-large with values ranging from 13.77 to 27.68. There was cracking, but no loss of adhesion in the 1-in. mandrel bend test. The time required before immersion after the last coat has been applied when the ambient temperature is 75 °F is a medium-to-long 7 days. System 19 performs very similarly to MIL-P-24441, type I, epoxy-polyamide, but this proprietary system has higher volume solids and it is a two-coat system. It would be used in the same applications as MIL-P-24441, type I, and would require a compatible weathering topcoat in partial immersion, for improved appearance.

56. Systems 20 and 21 are composed of 100-percent solids top and intermediate coats, and a 60-percent volume solids primer. System 21 has an added proprietary 4-percent volume solids pretreatment before priming. These bisphenol epoxy-aromatic amine coatings form dry film thickness of 55 to 56 mils. Neither of the systems exhibited blistering after completing 3582 hours of immersion in both the SW and FW immersion tests. Pulloff adhesion values were 285 lb/sq in. and 330 lb/sq in., respectively, for the controls. After the QUV exposure test, the values were 130 lb/sq in. and 213 lb/sq in., respectively. Both systems showed heavy chalking, with common chalk ratings of 4. Total color difference after immersion for both coating systems was in the low-to-medium range of 3.15 to 7.43. Total color difference after exposure in the QUV was a medium-to-high 17.10 to 18.90 for both coating systems. There was cracking and some loss of adhesion in the 1-in. mandrel bend test. Both systems require only 2 days before immersion after the final coat has been applied when the ambient temperature is 75° F. A compatible weathering topcoat would be desirable in partial immersion conditions for appearance.

Data Interpretation Comments

57. As even a cursory examination of the Elcometer pulloff adhesion data in Tables 5 and 7 suggests, this test has many variables. Although it is theoretically possible that pulloff adhesion values could increase after immersion or QUV exposure, the data and visual evidence indicate that vari-

ability in the test itself had a greater effect. Cutting around the dollies was a tedious and often difficult task. Damage to the coatings and/or glue line was largely responsible for the number of invalid tests that appear in Tables 5 and 7. Incipient failure of the adhesion of the epoxy adhesive to the topcoat of the coating system was also observed. The thickness of the test panels had the greatest influence on the actual adhesion values (in pounds per square inch) that were obtained. Thin (24 to 38 mils) test panels produce lower Elcometer pulloff adhesion readings than thick (approximately 125 mils) test panels. Thin test panels are not as flat, making it more difficult to achieve a uniform surface on which to adhere the dollies. Perhaps even more important, thin test panels are subject to flexing during the actual pulloff test. Consequently, to estimate the values that would reasonably be achieved in a "real-life" situation on steel plate, the values reported in this investigation would have to be subjected to unknown multipliers. Determining these multipliers is beyond the scope of this investigation.

58. Total color difference, ΔE^*ab, is the "distance" between two colors in L^*, a^*, b^* color space. (Graphic representations of L^*, a^*, b^* color space appear in Appendix A, Section 2.) Individual color shifts are described by ΔL^*, Δa^*, and Δb^*. For reference, a good commercial color match would have a ΔE^*ab of 0.5 to 1.5 units. Color shifts as a result of immersion or QUV exposure have two components; one as a result of immersion and one as a result of staining from corrosion products generated along the scribe lines or picked up from the bath. After QUV exposure, there is a color shift caused by exposure to ultraviolet light and an effect from chalking. (NOTE: When viewing the photographs in Appendix A, remember that the colors of the test panels may vary from the actual ones due to the photographic and color printing processes used to produce this report.)

59. The 1-in. mandrel bending test was included to provide relative elasticities and resistance to extreme bending stress of the coating systems tested. Obviously, if a hydraulic structure were to be subjected to the same relative degree of distortion, it would be severely, perhaps critically, damaged. As expected, polyurethanes and vinyls did better in this test than most of the other types of coatings. From a practical point of view, all of the coatings in the investigation showed acceptable performances in this test when their performances are weighed against the actual degree of bending they would likely encounter in actual use. However, where ability to resist flexing is a definite factor in coating selection, these results would be pertinent.

Estimated Costs

60. Table 2 contains figures on the estimated cost per square foot in dollars for the coating systems investigated. These figures were supplied by the manufacturers of the coating systems and include materials and applica-

tion, but exclude surface preparation. Because each coating system is different, an individual estimate is necessary for each application. The figures presented are based on "average" conditions and should be used only for general comparison.

The Investigation in Perspective

61. The test data indicate that a number of low-VOC coating systems should perform satisfactorily under FW immersion conditions. Almost one-third of the low-VOC coating systems tested should perform satisfactorily in SW immersion, as well. If appearance is important, most of these high-solids and 100-percent solids coating systems will require compatible weathering top-coats. This is one of the few drawbacks of this type of coating. However, the majority of hydraulic structures are in locations where protection is more important than appearance, so this should not prove to be a widespread or serious problem. A major advantage of many of the high-solids and 100-percent solids coating systems is that they require relatively short time periods between application of the final coat of putting the coated structure back into immersion service. This time period can be as short as 2 hours to a relatively short 4 days for many of the coatings that performed well in the investigation. There are positive economic implications in short downtime. For example, less lost electric power generation time translates into more power that can be sold. Short downtime also allows application at times which are more convenient and less costly to the public or private owners involved.

PART V: FIELD EVALUATION OF COATINGS

62. Following the laboratory evaluation, a number of the coatings having superior performance were applied to hydraulic structures for field evaluation.

63. System 3 was applied to radial gates on a Bureau of Reclamation structure. This material has a relatively short pot life making application by brush, roller, or single component airless equipment quite difficult. Satisfactory applications have been achieved using these methods by mixing only small amounts of the coating (2 gallons or less) at a time and working steadily. Thinning is unnecessary if application is by brush or roller. If thinning is required for spray, up to 5 percent Toluol may be used. Incorporation of the thinner should consist of adding half the volume of the thinner to each component before combining the components. The most effective method of application was found to be plural component airless equipment. No thinning was required for proper application. The target dry film thickness of 16 mils could be achieved using 2 coats regardless of application method provided the material had not been excessively thinned. After 1 year in service, the gates were still receiving excellent protection, however, the coating had chalked and looked somewhat "blotchy." There have since been other applications where appearance was considered of some importance. For these applications, two additional coats of a compatible moisture-cure aliphatic polyurethane coating were applied as weathering coats.

64. System 4 was applied to a tainter gate on the Mississippi River Lock and Dam 17. Application was conducted through the manufacturer by a licensed applicator. The product required an unusually large blast profile. Abrasive blasting using #4 flint grit produced an unacceptable surface profile of less than 4 mil. Therefore, the steel was reblasted using #7 flint grit. This produced an acceptable profile. (The profile measurement was in excess of the capabilities of testex tape and is thought to be in the 6 to 8 mil range.) Application was conducted using Graco plural component airless equipment. The components were pumped from the container, through heaters, and into the main triple cylinder pump unit. (Three cylinders were necessary for 2:1 mix ratio.) The components passed through a heated hose line and were finally combined in a series of static mixers located between the body and the tip of the airless spray gun. The gun was also supplied by a third hose containing methylene chloride solvent to flush material from the mixers and tip whenever the application was interrupted. Application was plagued by equipment problems. Improper cleaning of a transfer pump may have allowed the isocynate component to crystallize thus requiring replacement of the pump and hoses. Unsatisfactory temperature controls caused improper mixing, resulting in a considerable amount of lost time and material. These problems may also be responsible for some of the early failures noticed with the coating. After

the problems had been addressed, further application progressed rapidly. Multiple coats can be used to attain any desired thickness; however, experience and good applicator techniques are necessary to attain a reasonably uniform thickness. In the test areas where a 50 mil dry film thickness was desired, measured thicknesses ranged from 27 to 97 mils with the majority of the readings in the 40 to 55 mil range. The material was set-to-touch in less than an hour; however, it was still soft enough to be dented with the thumb nail the following day. After one winter it was found that many of the rivet heads on the downstream waterline area were showing bare steel. After the second winter, these rivet heads were almost 50 percent bare. There were a few scratches through the coating and there was a significant area of intercoat delamination. This delamination probably was the direct result of the application problems. There was no blistering or other form of coating failure in areas of low abrasion.

65. System 7 was applied to the downstream face of a tainter gate on the Mississippi River Lock and Dam 17. The system is composed of two coats of quite typical two-component epoxies. The materials were applied using a single component, Graco airless unit having a 619 tip. Thinning was not necessary. The primer and the topcoat were applied on successive days. Thickness of the primer ranged from 3.8 to 5.5 mils. Total thickness ranged from 7.8 to 15 mils with most readings in the 9 to 12 mil range. After the first winter, the coating appeared to be in near new condition having no signs of defects or damage. After the second winter, however, it was evident that significant failure was taking place. Rivet heads at the downstream waterline were approximately 40 percent bare and the entire underwater area was showing signs of generalized rusting to the extent that the gray coating has taken on a light brownish appearance. Atmospheric areas were showing signs of mild chalking but no other defects.

66. System 9 was initially selected for field application. However, researchers learned that the manufacturer is no longer in business.

67. System 10 was applied to the downstream face of a tainter gate on the Mississippi River Lock and Dam 17. The system is composed of two coats of quite typical two-component epoxies. The materials were applied using a single component, Graco airless unit having a 619 tip. Thinning was not necessary. The primer and the topcoat were applied on successive days. Thickness of the primer ranged from 6.0 to 9.0 mils. Total thickness ranged from 11.0 to 18.0 mils with most readings in the 14 to 15 mil range. After the first winter, the coating appeared to be in near new condition having no signs of defects or damage. After the second winter, however, it was evident that failure was taking place. Rivet heads at the downstream waterline were approximately 25 percent bare and the entire underwater area was showing initial signs of generalized rusting. Atmospheric areas were showing signs of chalking but no other defects.

68. System 11 was applied to radial gates on a Bureau of Reclamation Structure. The system consists of multiple coats of a typical two-component epoxy. The system was applied using a single component airless unit. No thinning was necessary. Application properties were excellent. During one portion of the application, the weather was quite cool so a manufacturer's recommended accelerator was added to the coating before application. The coating was applied in 5 coats producing a minimum dry film thickness of 16 mils. In this application, each coat was a different color so the depth and rate of wear experienced in service could be monitored. In another application, the material was applied to a minimum of 16 mils dry film thickness in two coats. And a two-component polyurethane topcoat was added to improve weathering characteristics. The time of exposure of these systems has not been long enough to determine performance characteristics.

PART VI: CONCLUSIONS

69. The most severe laboratory test was the SW immersion test. Seven coating systems of varied generic types survived this test and the FW immersion test without blistering. They outperformed the widely used System 15 (VR-6 vinyl resin coating system) and System 18 (MIL-P-24441, type I, epoxy-polyamide coating system), both of which blistered in the SW immersion test. None of the coating systems that blistered in the FW immersion test successfully resisted blistering in the SW immersion test. The coating systems that did not blister in either immersion test were:

- System 4 - A nonelastomeric polyurethane, self-priming, target dry film thickness (TDFT) 50 mils.
- System 8 - An epoxy-polyamide primer containing zinc chromate pigment with an epoxy-polyamide intermediate coat and an epoxy-cycloaliphatic polyamine, modified, topcoat, TDFT 9 mils.
- System 9 - An epoxy-polyamine, self-priming (can be applied under water), TDFT 9 to 13 mils.
- Systems 16 and 17 - Highly modified styrene polyesters, 2 percent MEK peroxide hardener, primer, intermediate coat, and topcoat, TDFT 26 to 34 mils.
- Systems 20 and 21 - Bisphenol epoxy-aromatic amine; primer, intermediate coat, and topcoat (System 21 received a proprietary pretreatment before the primer was applied), TDFT 55 to 56 mils.

70. The commonly used VR-6 vinyl resin and the MIL-P-24441, type I, epoxy-polyamide coating systems performed satisfactorily (did not blister) in the FW immersion test, as did the following 11 high-solids and 100-percent solids coating systems of varying generic compositions:

- Systems 1 and 23 - Elastomeric aromatic polyurethane, isocyanate polyol primer, TDFT 32 mils.
- Systems 2 and 24 - Elastomeric aromatic-aliphatic polyurethane, isocyanate polyol primer, TDFT 32 mils.
- System 3 - Epoxy-amine, self-priming, TDFT 16 mils.
- System 7 - Epoxy-polyamide primer with an epoxy-cycloaliphatic polyamine topcoat, TDFT 9 mils.
- System 10 - Cycloaliphatic amine cured epoxy, primer and topcoat, TDFT 10 to 13 mils.
- System 11 - Epoxy-polyamide, self-priming, TDFT 16 mils.
- System 12 - Coal-tar epoxy, self-priming, TDFT 20 mils.
- System 13 - Epoxy-polyamide self-priming, TDFT 12 mils.
- System 19 - Proprietary primer and topcoat system based on MIL-P-24441, type I, but with higher volume solids, TDFT 8 to 13 mils.

71. Film thickness was not a significant factor in determining coating performance in the immersion tests or in the QUV accelerated weathering tests. The generic type of coating system, not the film thickness, was the major factor determining performance in the 1-in. mandrel test. Six polyurethane and three vinyl coating systems of varying thicknesses had no cracking or loss of adhesion; only one epoxy coating system exhibited these results. No clear pattern of control adhesion values and their connection to film thickness values emerged from the Elcometer pulloff adhesion tests. Film thickness could, however, be of more significance in the field. If two coating systems have the same yearly rate of chalking, erosion, etc., the thicker coating will have a greater remaining thickness at any given time.

72. An appreciable number of the high-solids and 100-percent solids coating systems tested are suitable candidates for further testing in the field, based on the laboratory testing conducted during the investigation. These coating systems are specifically identified in Part VII: RECOMMENDATIONS. The coating systems recommended are ones that did not blister in the SW and/or the FW immersion tests. The overall laboratory testing data for these systems indicate they will perform at least as well as the VR-6 vinyl coating system (System No. 15) and the MIL-P-24441, type I, coating systems (System No. 18). If the same generic type of coating systems have equal, or very nearly equal, performance properties, one coating system should be chosen to represent the generic group.

73. This investigation has provided data on immersion resistance, accelerated weathering resistance, flexibility, pot life, recoating and curing times, methods of application, generic description, recommended film thickness, VOC content, volume of solids, and sequence of coats (Tables 1 through 8). This data can be used to write performance specifications. Adhesion values were also obtained and could be used subject to a caveat concerning the effect of test panel thickness.

74. The data from the QUV accelerated weathering test indicate that some of the coating systems weather reasonably well, from an appearance standpoint, but an appreciable number of systems do not. Appearance is of secondary importance to performance in most hydraulic structure applications. However, where appearance above the waterline is important, practically all manufacturers have available, or can recommend, compatible, good weathering topcoats.

75. Many of the high-solids and 100-percent solids coating systems tested require special application equipment (special in the sense that the equipment differs in one or more features from "conventional" air and airless spraying equipment). This equipment is available from major equipment suppliers and is already being used by a number of industrial coating contractors. Some of the manufacturers of the coatings tested have licensed or approved applicators for their coating systems. However, all of the

systems tested must be properly applied over correctly prepared surfaces if they are to perform satisfactorily, or to reach their maximum potential. In this respect, they do not differ from "conventional" coating systems.

76. The higher costs associated with high-solids and 100-percent solids coating systems can be illusory. Higher material and/or application costs can be offset by shorter downtimes and lower long-term coating costs. Cost analysis of these coating systems should be based on a life-cycle basis, cost per square foot per year of satisfactory service, not initial cost.

77. The data acquired in the investigation provide control points for the performance recorded under the sets of conditions and film thicknesses in force at the time of testing. These control points will prove useful for future investigations of the effects of changing the film thickness, number of coats, conditions of testing, etc., for any of the coating systems in the investigation.

78. The field evaluation work has highlighted some important concerns relating to both application and performance. Perhaps the most important concern is the ease of application of some of the modern coatings. Whereas coatings 3, 7, 10, and 11 were easily mixed and applied using common single component airless spray equipment and indeed could have been applied by other methods such as brushes and rollers, System 4 proved difficult to apply even for a manufacturer's licensed applicator. It appeared to require very precise mixing ratios, temperature controls, and meticulous cleaning of equipment. It is doubtful that a Corps of Engineers inspector could have recognized application irregularities that might have resulted in coating failure. In fact, the coating manufacturer must not have recognized the defect that lead to the observed delamination problem. If a Corps of Engineers installation elects to have a coating system of this nature applied, the contract should include manufacturer liability requirements to ensure satisfactory application and performance.

PART VII: RECOMMENDATIONS

79. Based on laboratory testing, the following coating systems are recommended for field testing under either SW or FW immersion conditions:

- System 4 - A nonelastomeric polyurethane, self-priming.
- System 16 or 17 - Highly modified styrene polyesters; 2 percent MEK peroxide hardener; primer, intermediate coat, and topcoat. System 17 has an intermediate coat containing a silica-type filler material; System 16 has an unfilled intermediate coat. System 17 had slightly higher control and QUV Elcometer pulloff adhesion values.
- System 20 or 21 - Bisphenol epoxy-aromatic amine; primer, intermediate coat, and topcoat. System 21 has a proprietary pretreatment before priming. System 20 has no pretreatment. System 21 had slightly higher control and QUV Elcometer pulloff adhesion values.

80. Based on the laboratory testing the following coating systems are recommended for field testing under FW immersion conditions only:

- System 1 - An elastomeric aromatic polyurethane; isocyanate polyol primer applied with peaks of blasting profile covered, but profile still showing.
- System 2 or 24 - Elastomeric aromatic-aliphatic polyurethanes; isocyanate polyol primer. System 24 differs from System 2 in that System 24 has the primer applied and its film thickness measured conventionally instead of being applied like the primer in System 1.
- System 3 - An epoxy-amine, self priming.
- System 7 - Epoxy-polyamide primer with an epoxy-cycloaliphatic polyamine topcoat.
- System 10 - Cycloaliphatic amine cured epoxy, primer and topcoat. (Of the coating systems tested, System 10 was the most similar in application properties to a conventional low-solids epoxy coating system.)
- System 11 - An epoxy-polyamide, self-priming.

81. The results of the investigation suggest additional avenues of exploration. For example, the combination of compatible elements of different generic systems to upgrade such properties as immersion, abrasion, and weathering resistance should be explored. Such systems already exist for bridges and other structures, a notable example being the well known inorganic zinc/epoxy/aliphatic polyurethane coating system. Coating manufacturers as well as coating users need to be involved in this type of an investigation.

82. The lack of universally accepted and appropriate performance specifications is a major difficulty experienced when specifying the use of high-solids and 100-percent solids coatings. The data acquired during this investigation could be used, in part, to create such specifications. Specifications and standards writing organizations such as the Steel Structures

Painting Council, ASTM, and the National Association of Corrosion Engineers should be encouraged to develop and approve specifications for these types of coating systems as a high priority activity, as should appropriate groups within Government. Another major difficulty is the lack of quicker accelerated test procedures for high-performance coatings, such as the coatings in this investigation. Efforts to develop better and quicker accelerated test procedures for high-performance coatings should be supported.

REFERENCES

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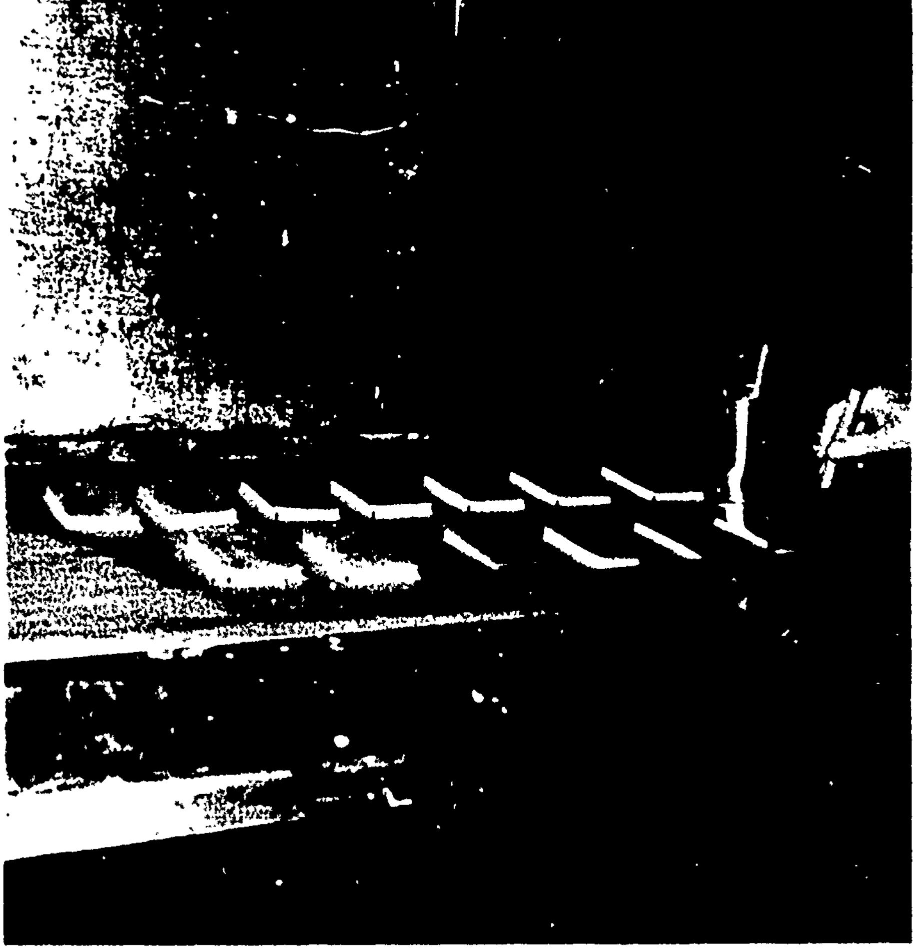
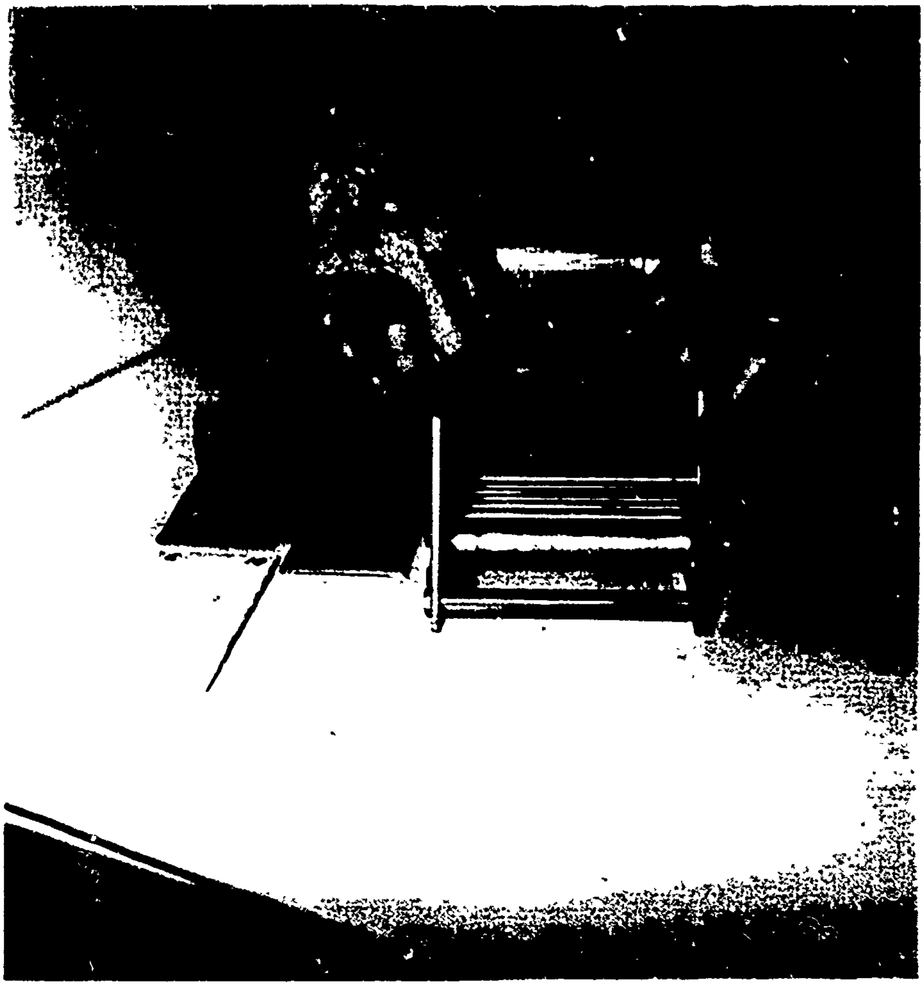
APPENDIX A: PHOTOGRAPHS OF THE LABORATORY EQUIPMENT AND TEST PANELS

Note: The photographs may not represent the exact colors of the test panels. This is partially due to color shifts that take place during printing and reproduction, and partially due to lighting, shooting angles, etc., that maximized the visible effects of the tests. However, the best possible representation is provided.

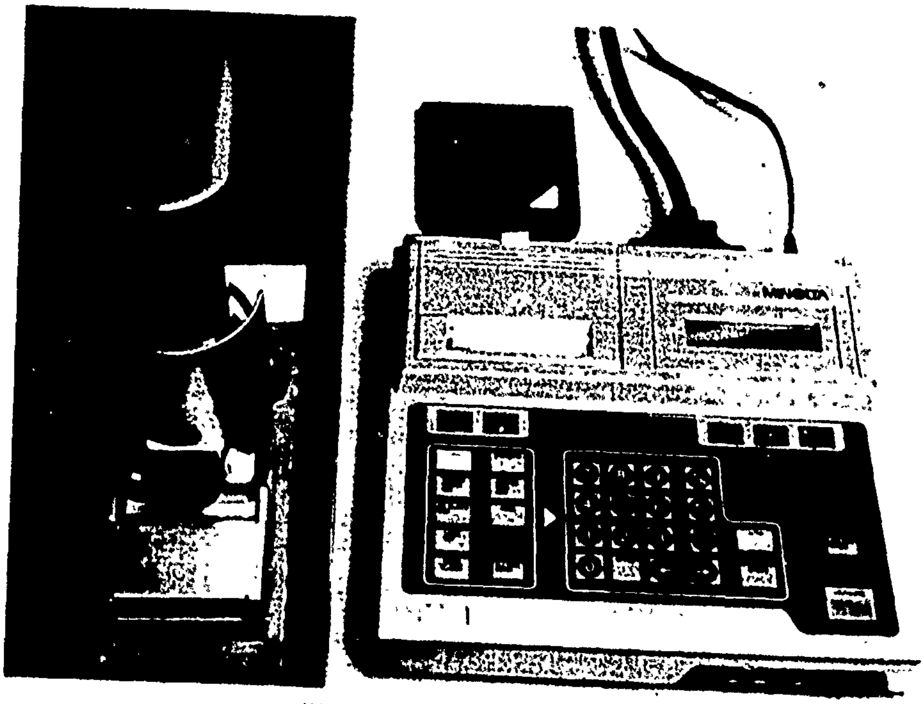
Section 1: Laboratory Equipment



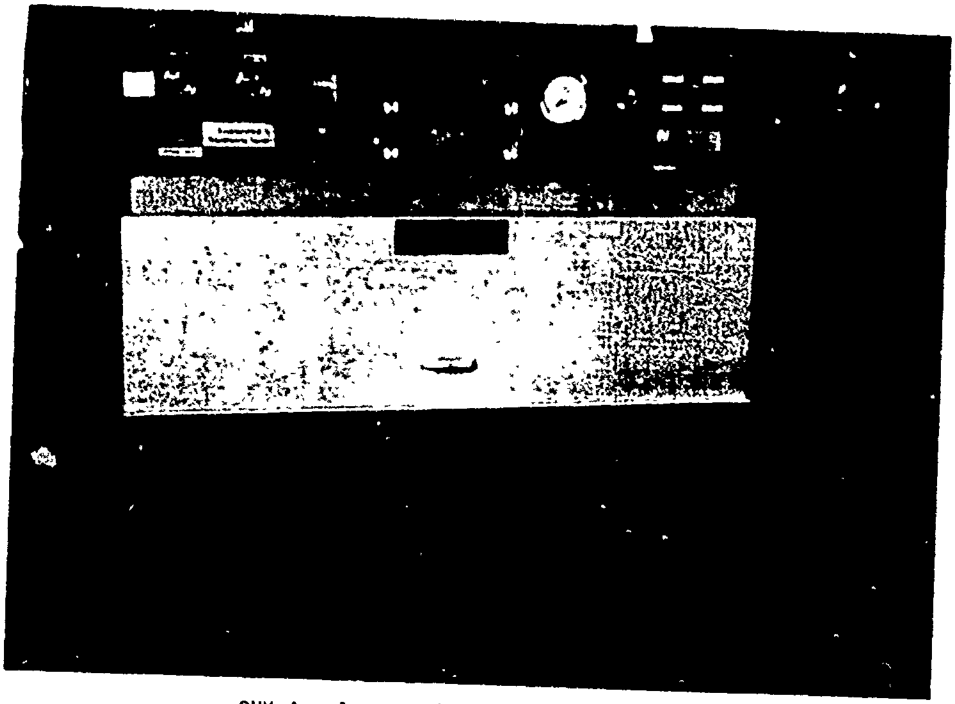
Application of a Coating System to the Testing Panels



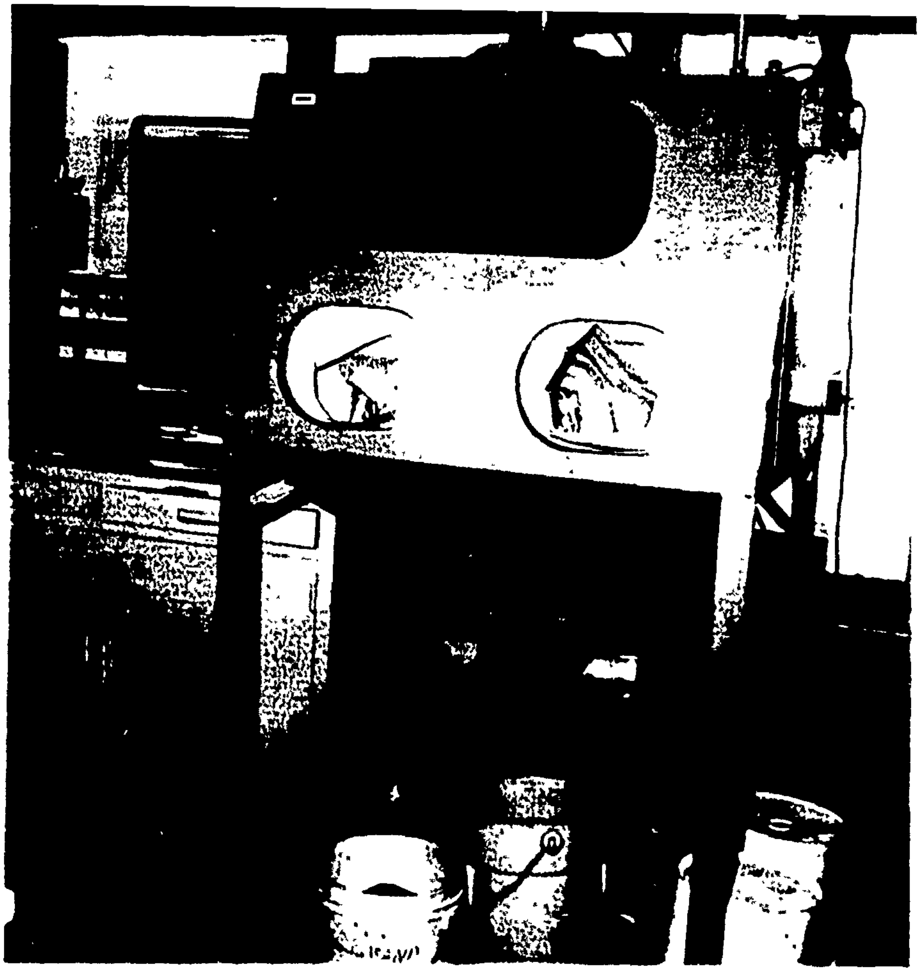
1-Inch Mandrel Bend Test



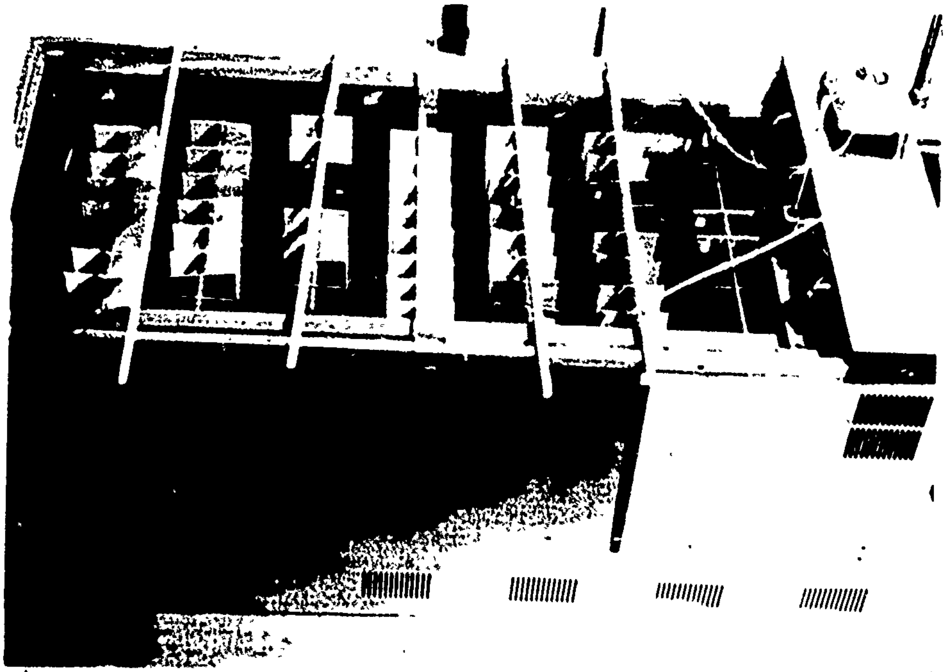
Minolta CR-200b Chroma Meter



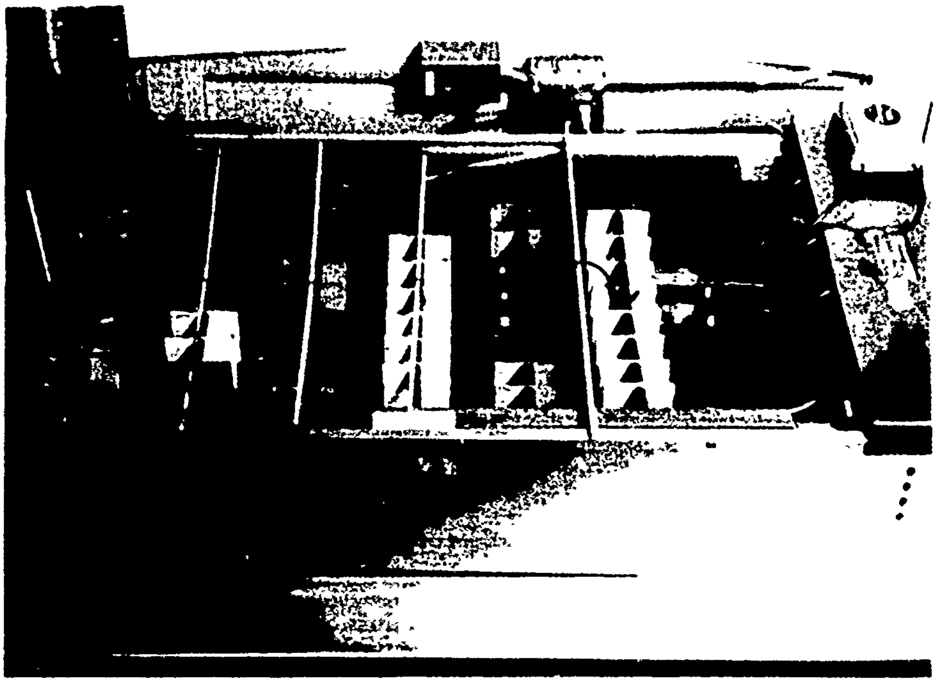
QUV. Accelerated Weathering Apparatus


Inland UNI-BLASTER SB-7 Media Blasting Cabinet


Inside View of the Media Blasting Cabinet - Testing Panel in Position



Saltwater Immersion Test



Freshwater Immersion Test

Elcometer Pull-off Adhesion Tester with Accessories

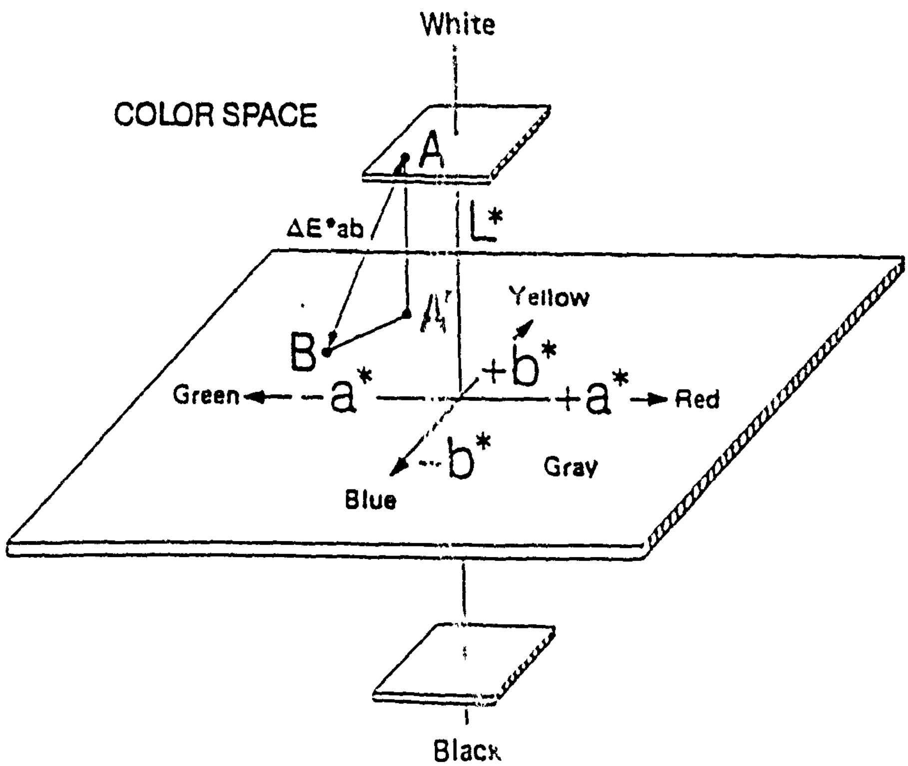
Section 2: L*,a*,b* Color Space Illustrations

Note: These illustrations appear in Precise Color Communication (figures 7 and 8) and Chroma Meta CR-200, Cr-231 (page 57) published by the Minolta Corporation, Meter Division, 101 Williams Drive, Ramsey, New Jersey 07446. The illustrations are used with the permission of the Minolta Company.

Total color difference ΔE^*_{ab} is also measured using the $L^*a^*b^*$ color coordinates and defined by the equation below.

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

$L^*a^*b^*$ color space and color difference ΔE^*_{ab}



A: Target color
B: Sample's color
A': Target color at the same lightness level as sample's color

Fig. 7: L*a*b* color chart (hue and chroma)

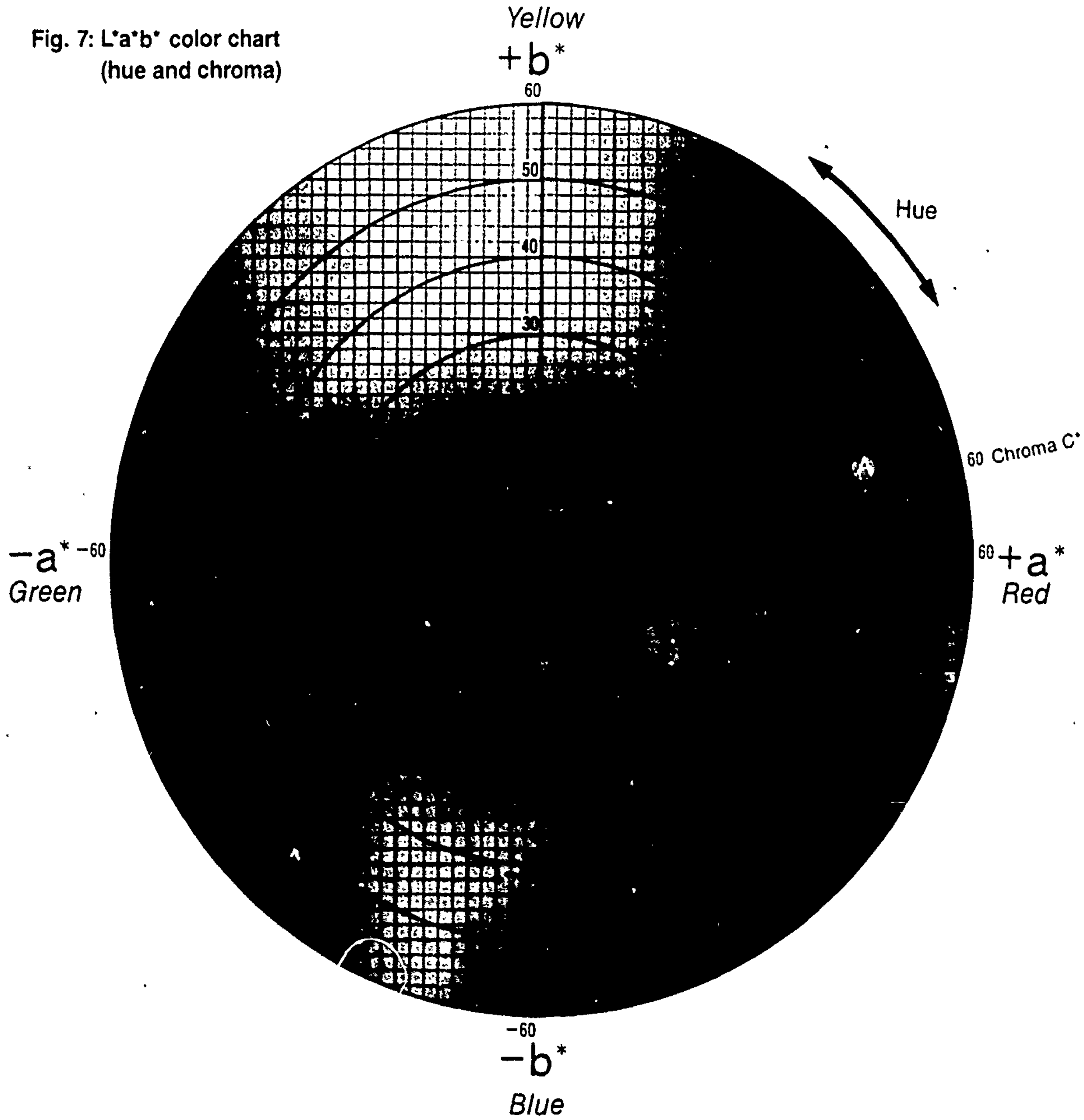
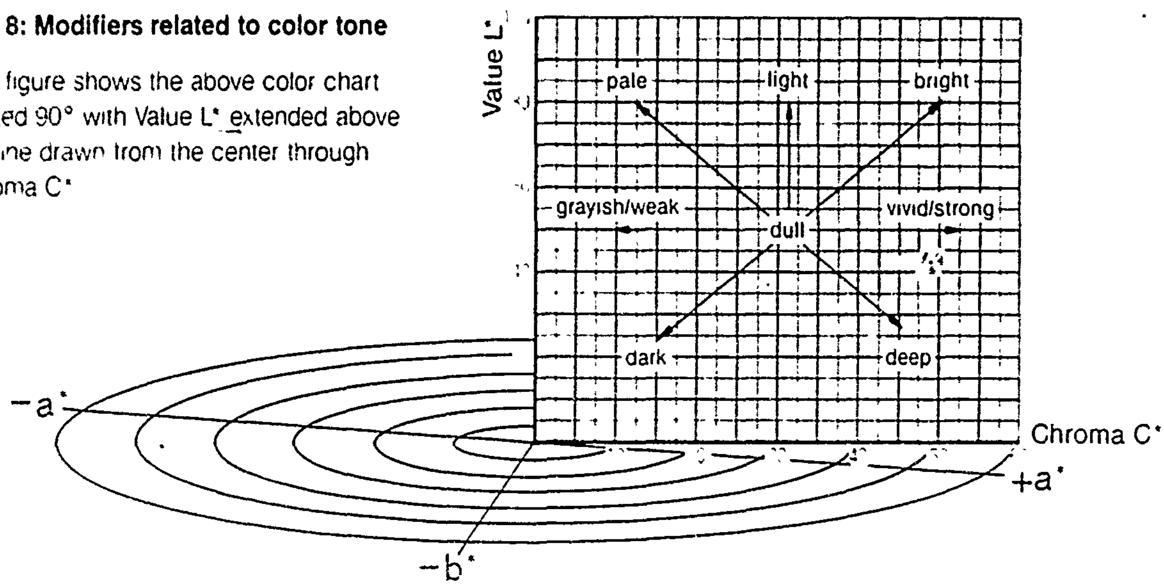


Fig. 8: Modifiers related to color tone

This figure shows the above color chart rotated 90° with Value L* extended above the line drawn from the center through Chroma C*



Section 3: Immersion Tests

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System No. 1 - SWI - Panel No. 2


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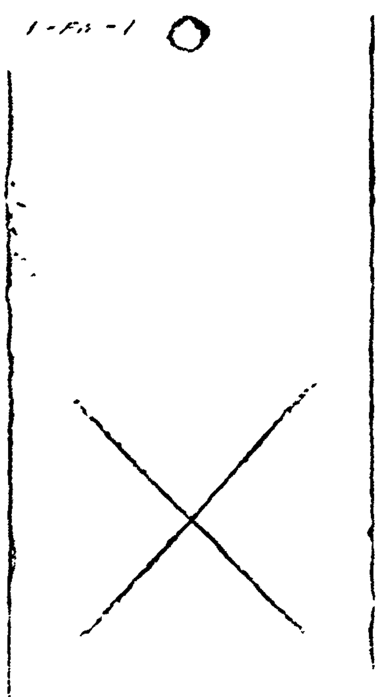
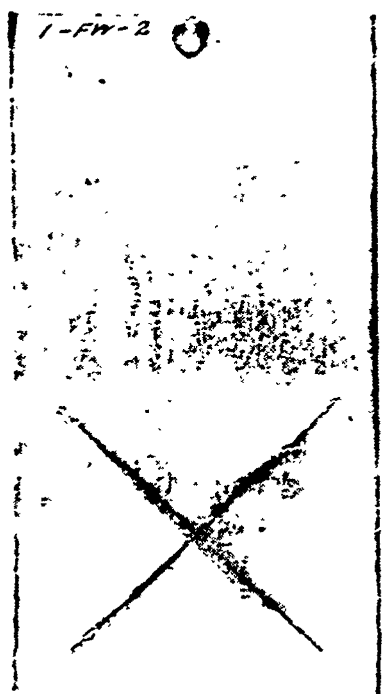
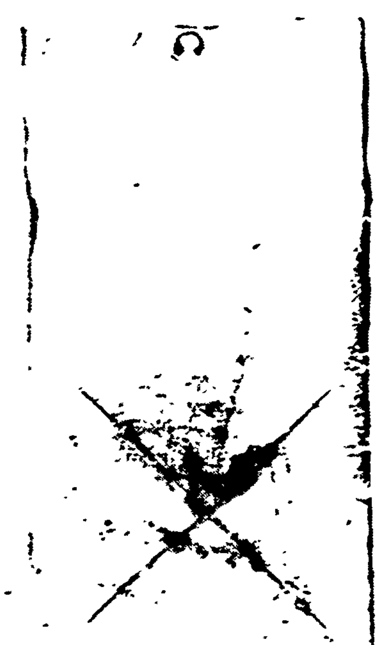
System No. 2 - SWI - Panel No. 2







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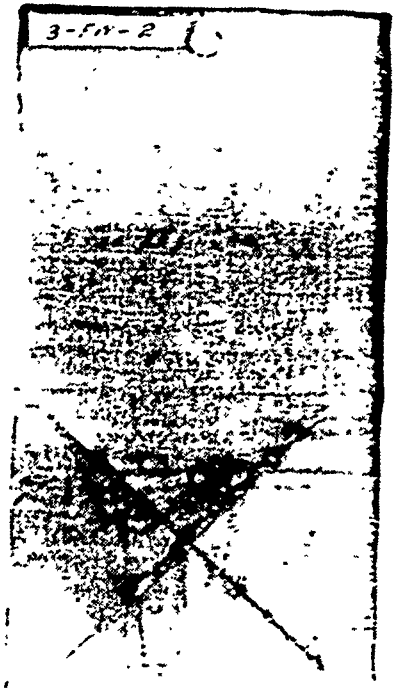
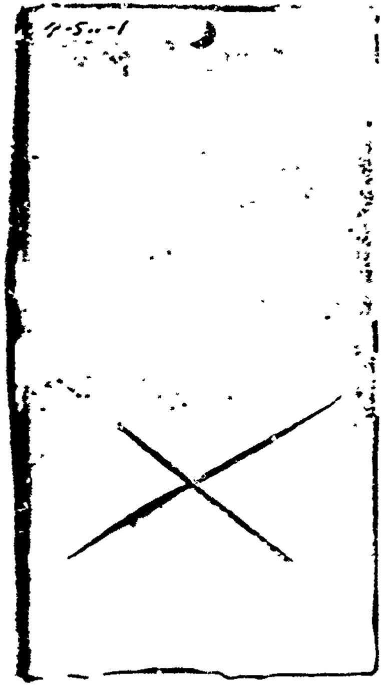
System No. 3 - SWI - Panel No. 2





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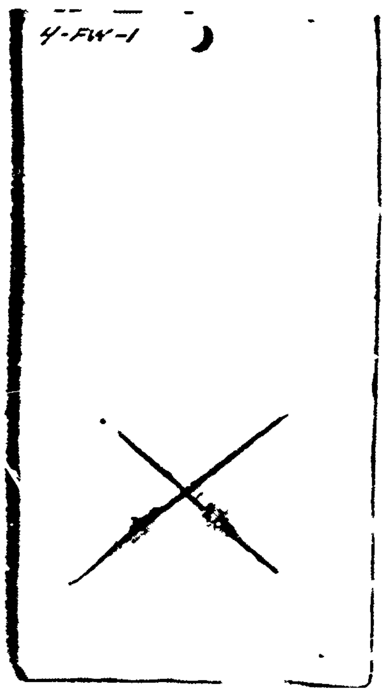

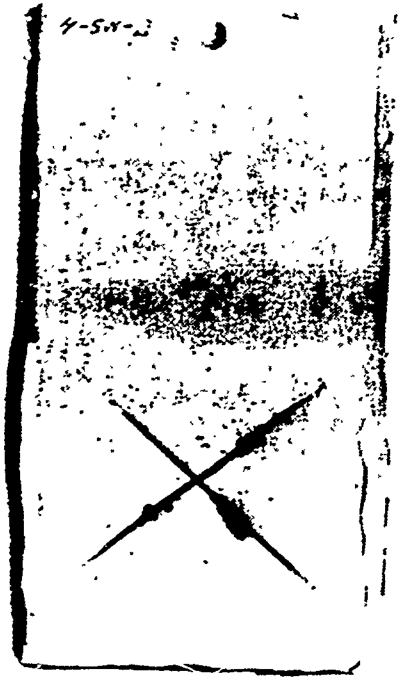

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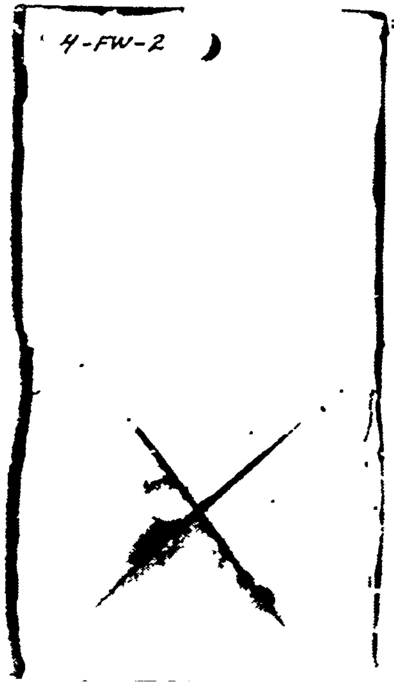

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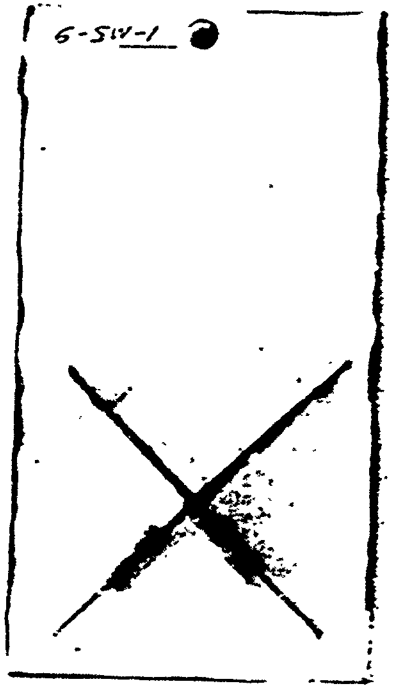

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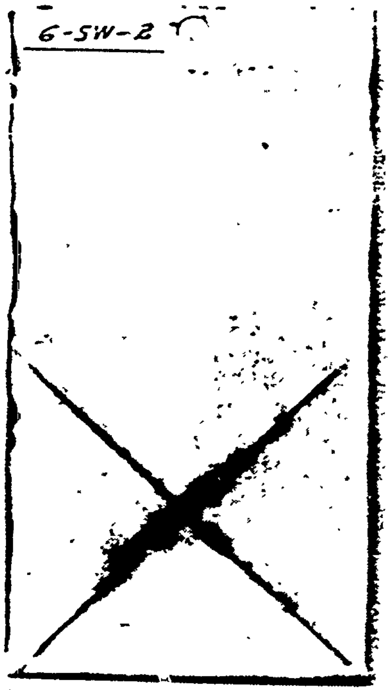

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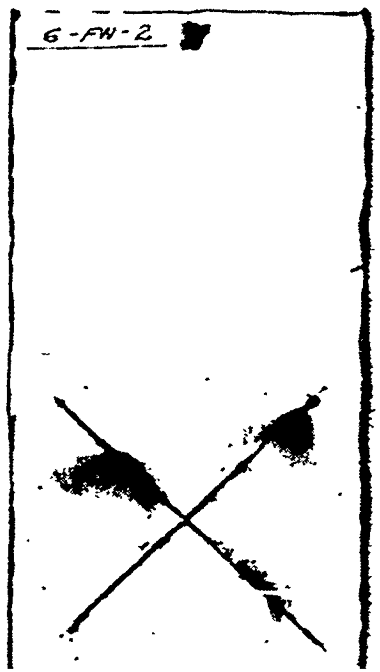

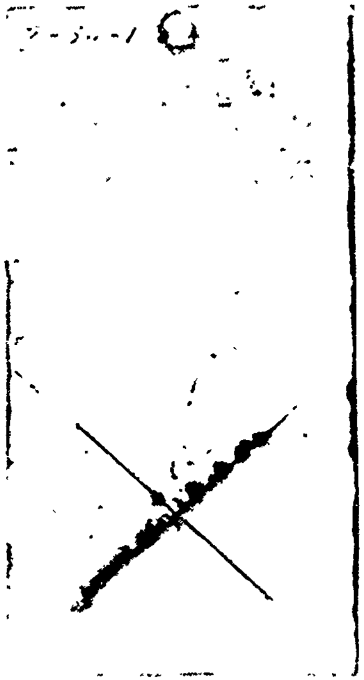

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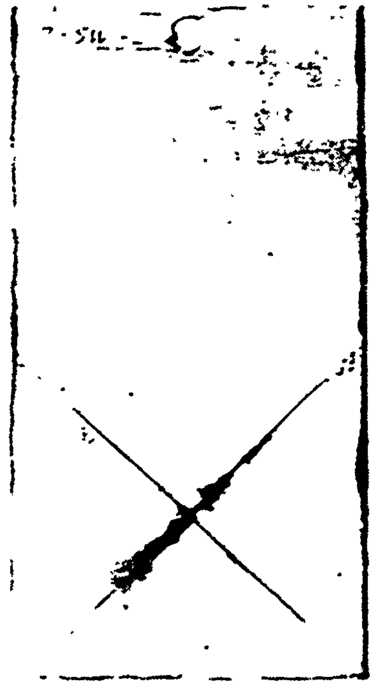

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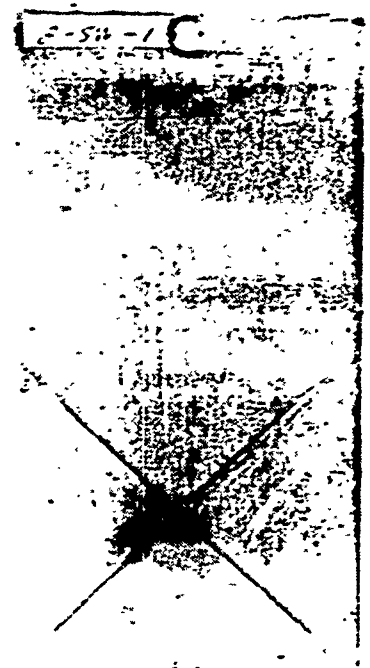

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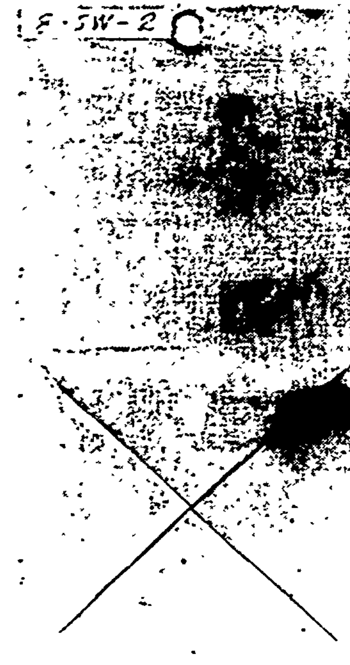

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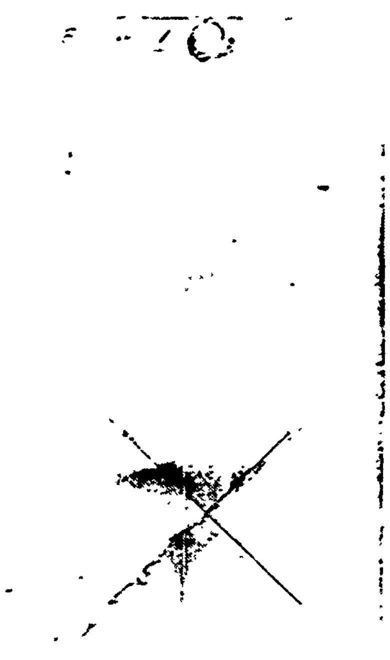

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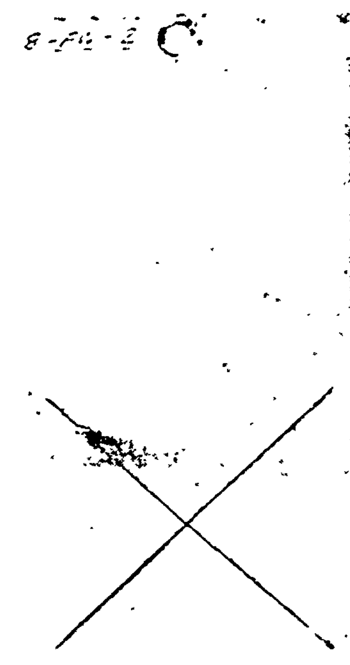

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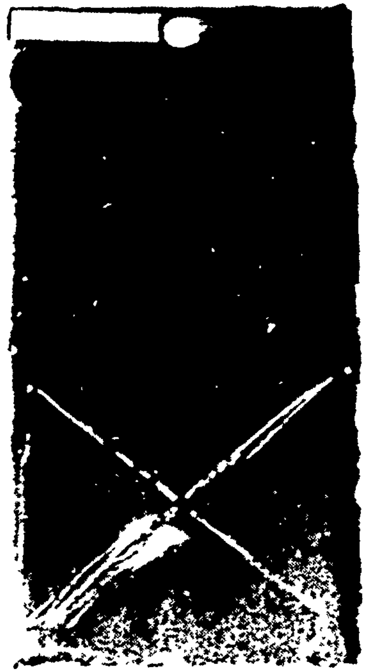

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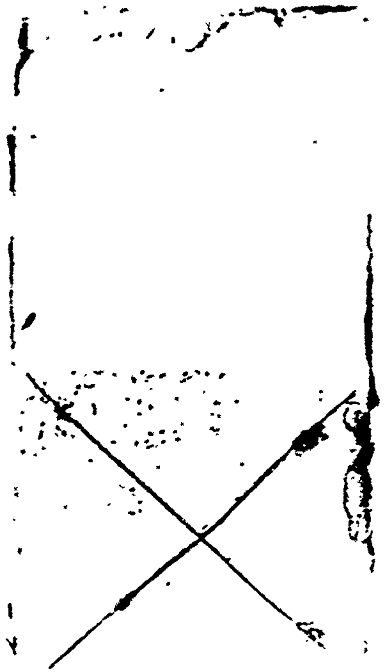

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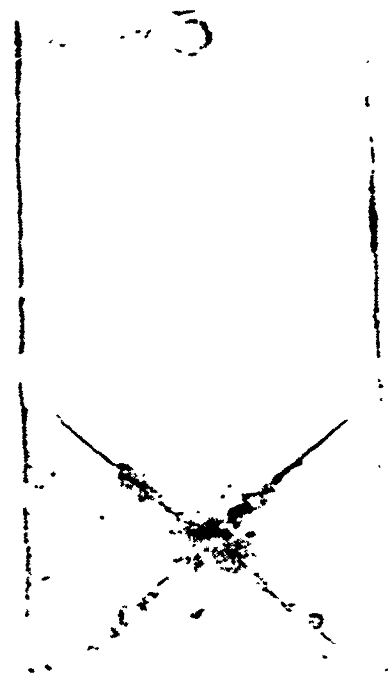

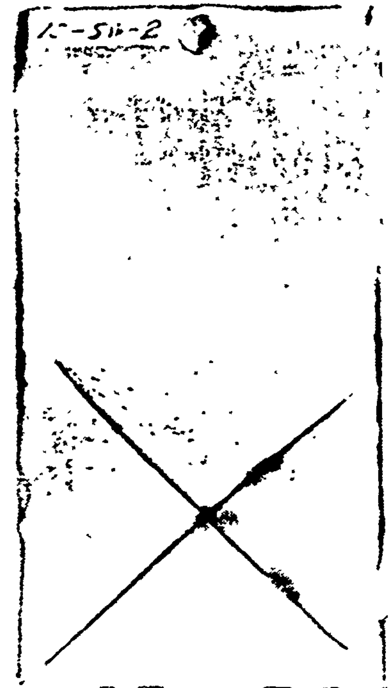

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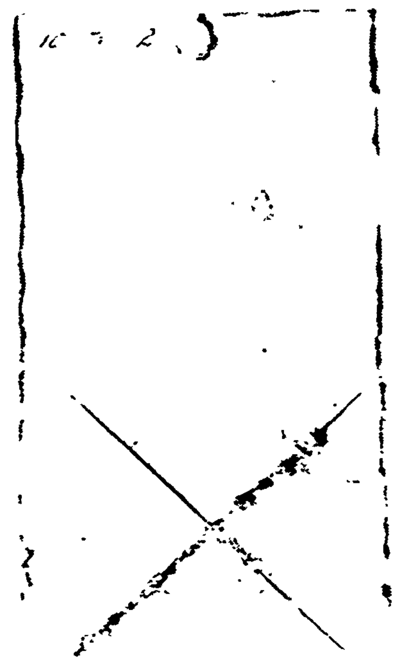

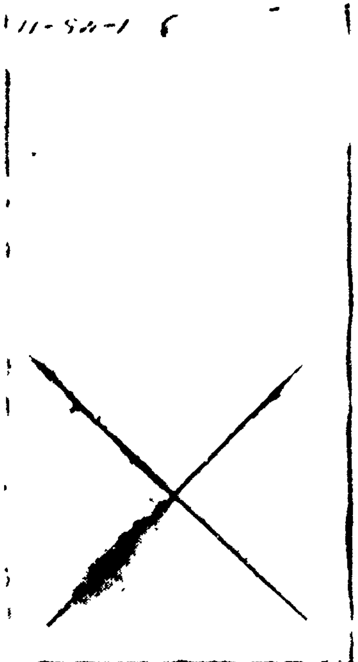

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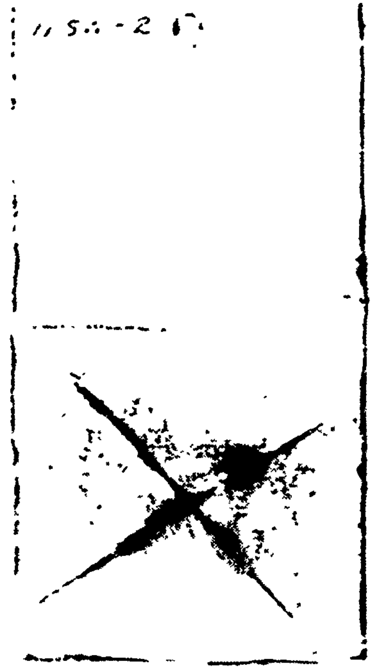

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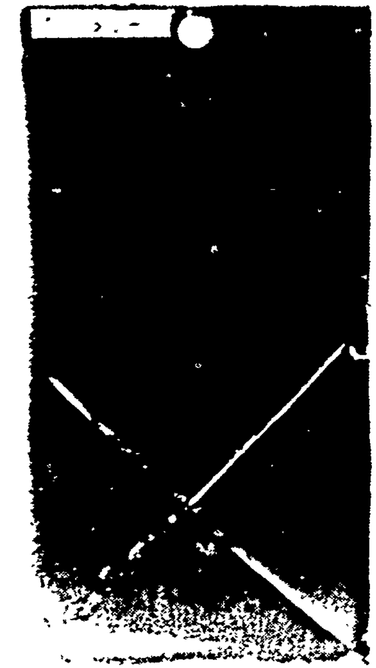

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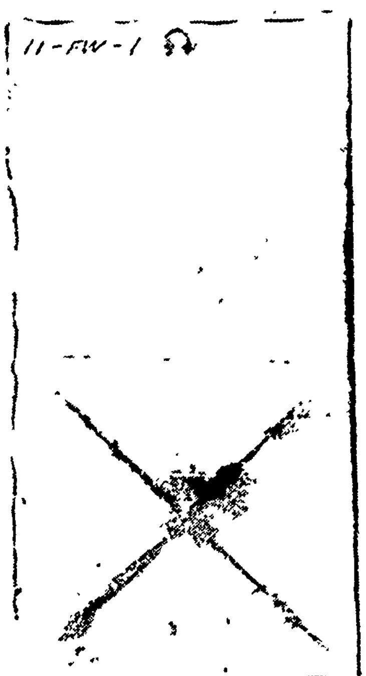

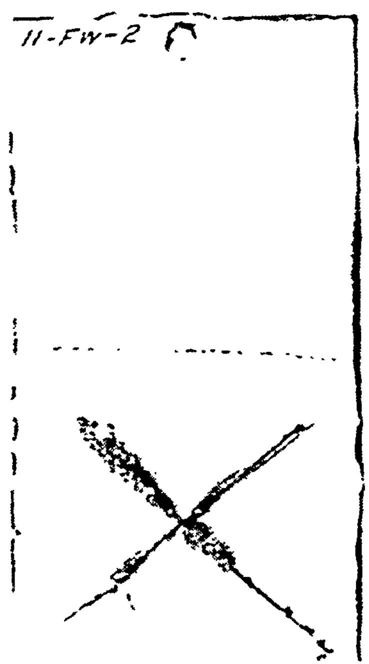

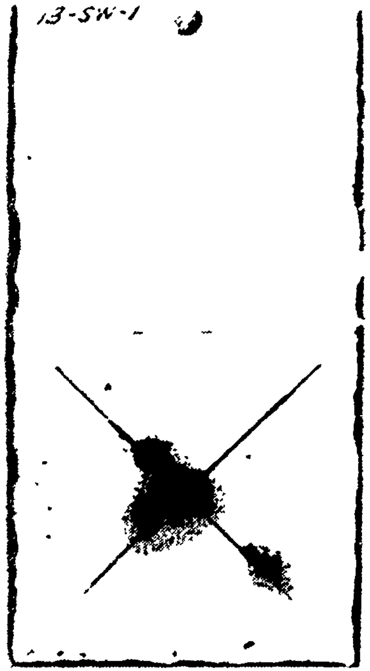

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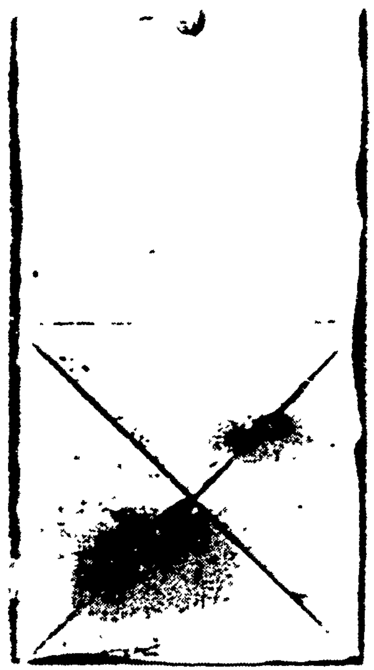

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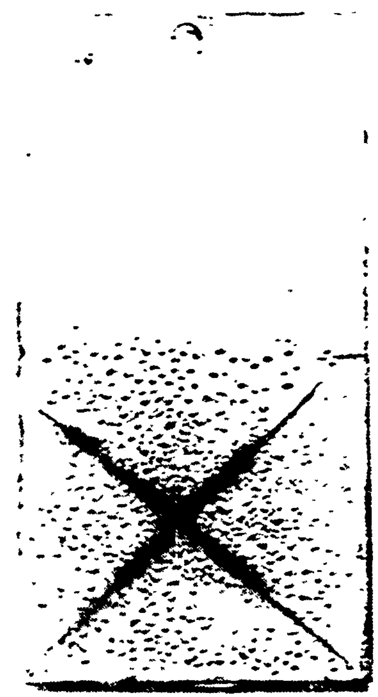

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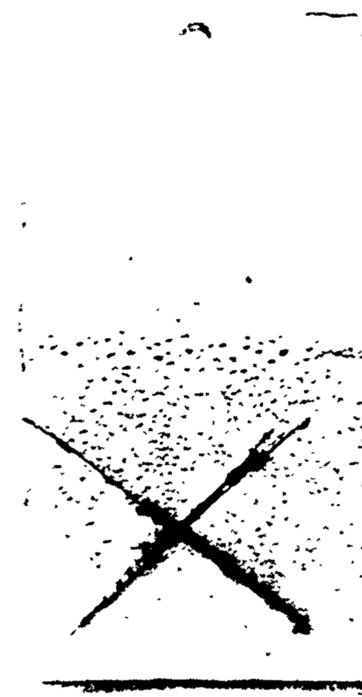

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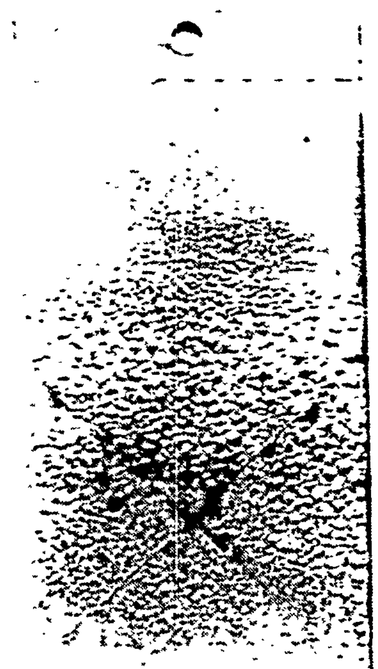

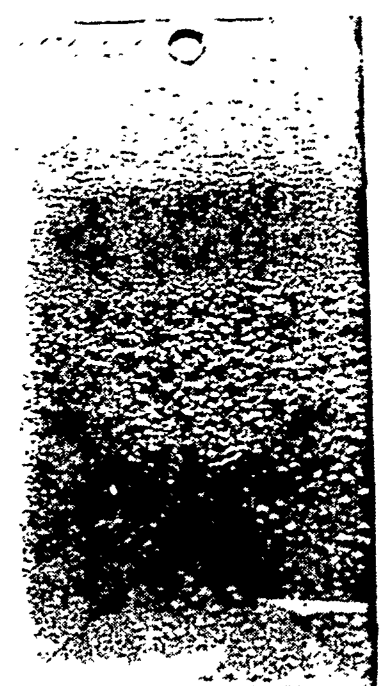

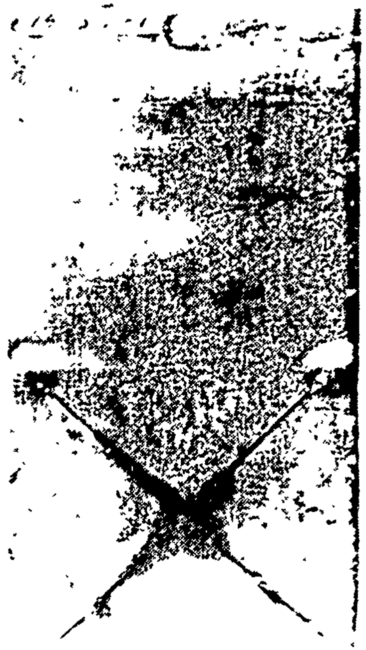
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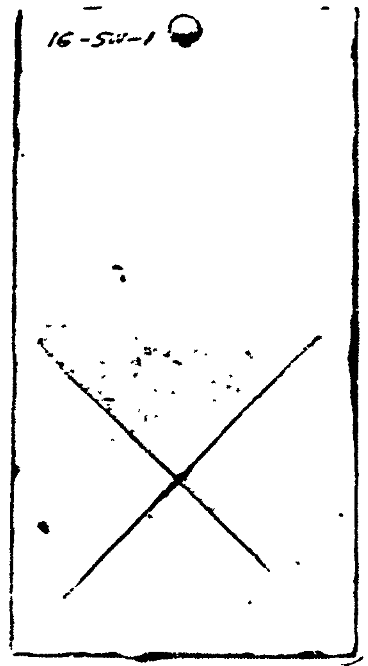

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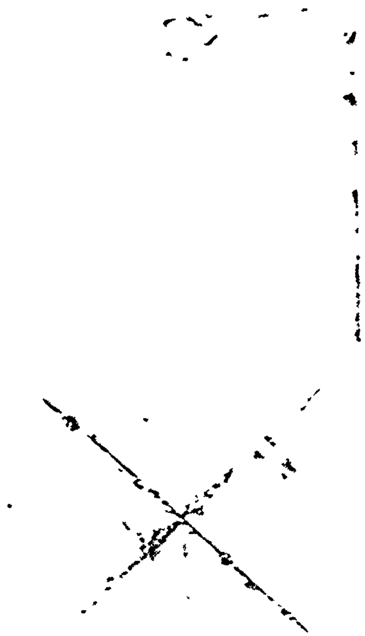
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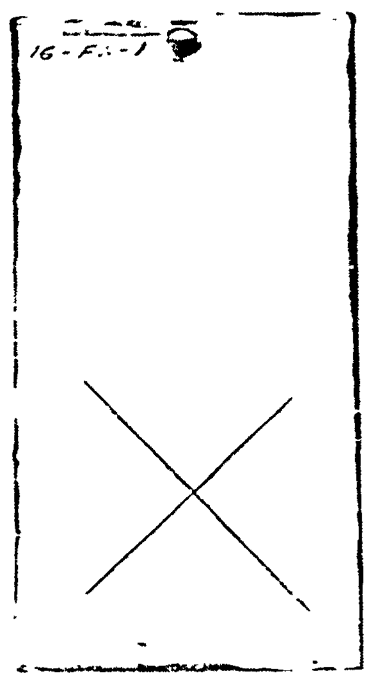
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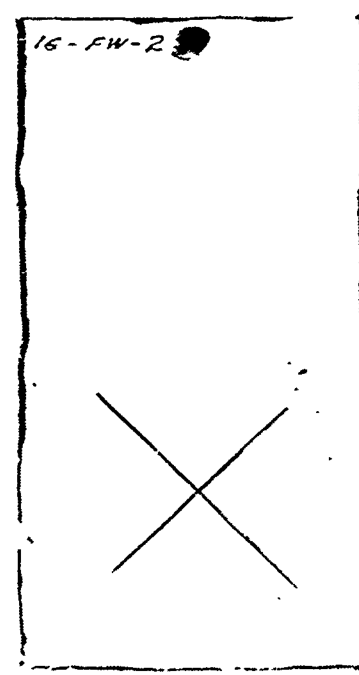

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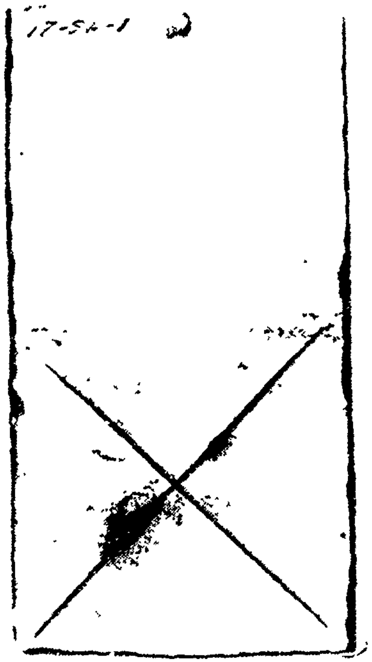

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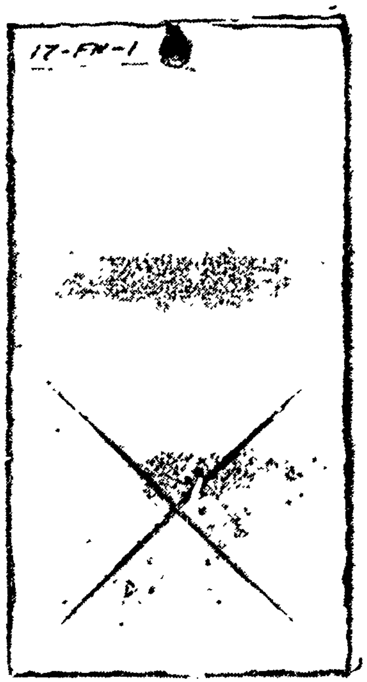

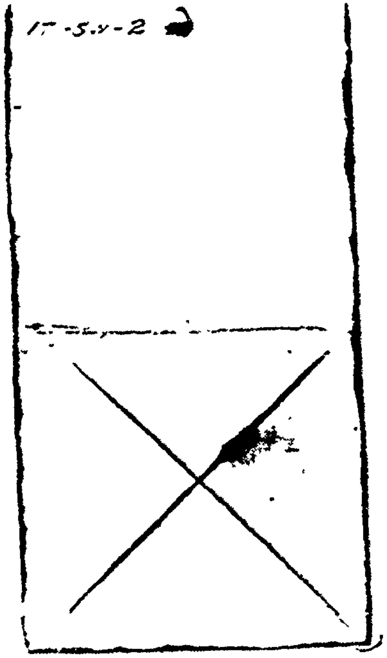

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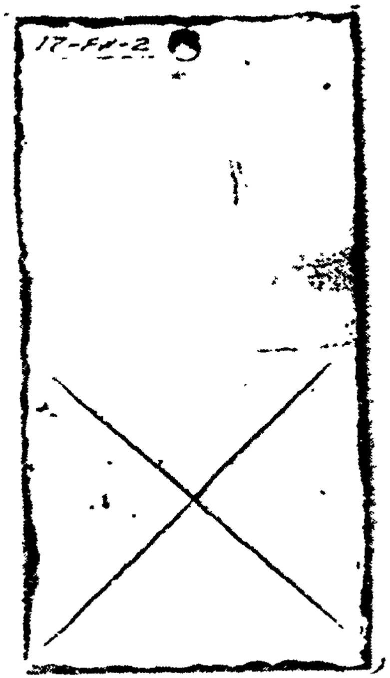

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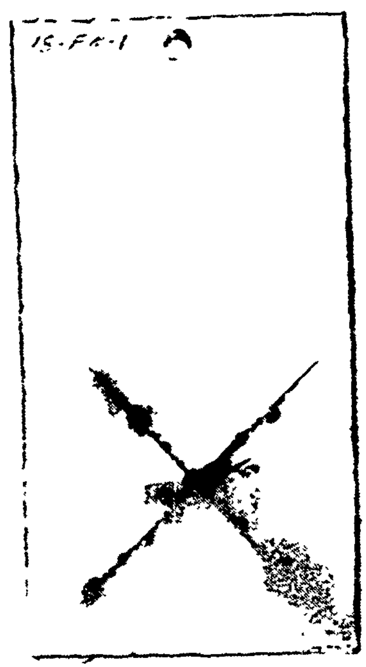

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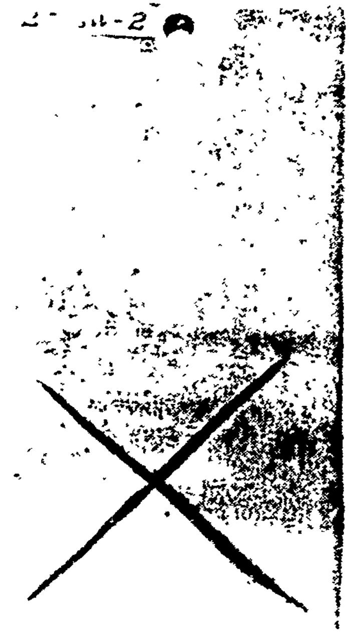

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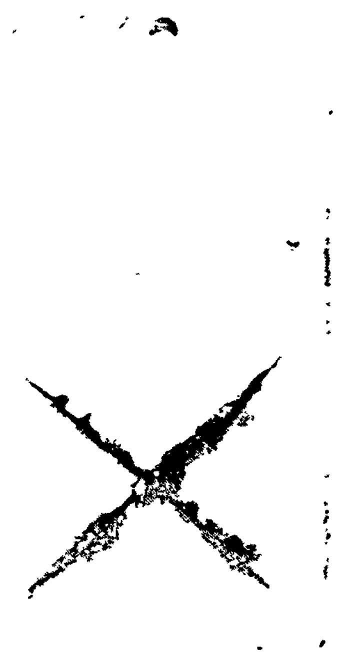

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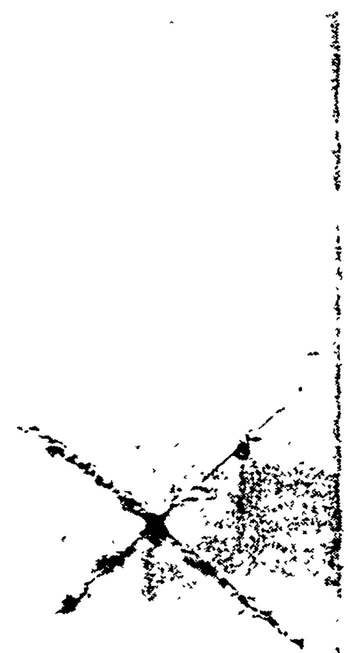
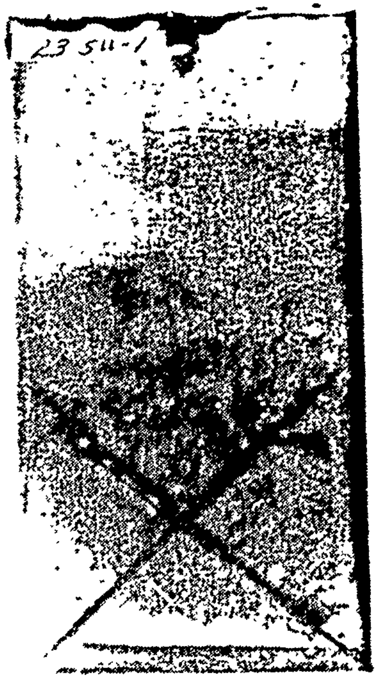
System No. 22 - SWI - Panel No. 2





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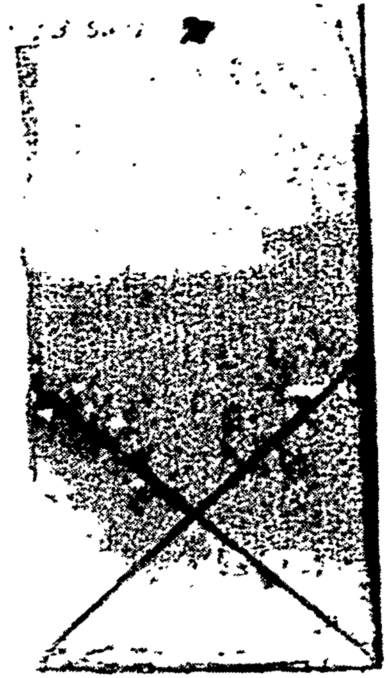

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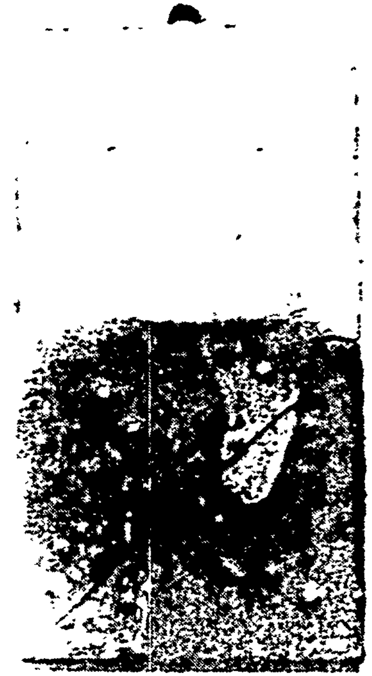

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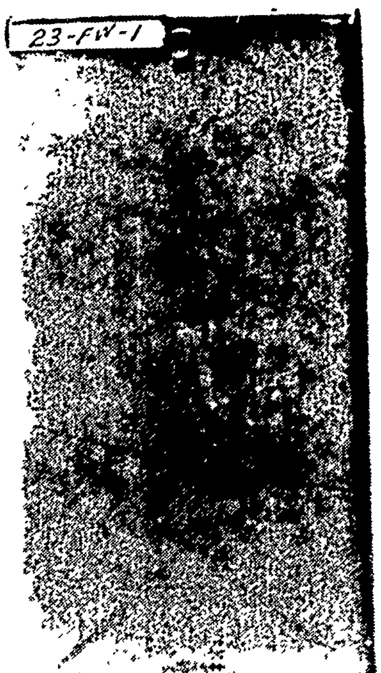

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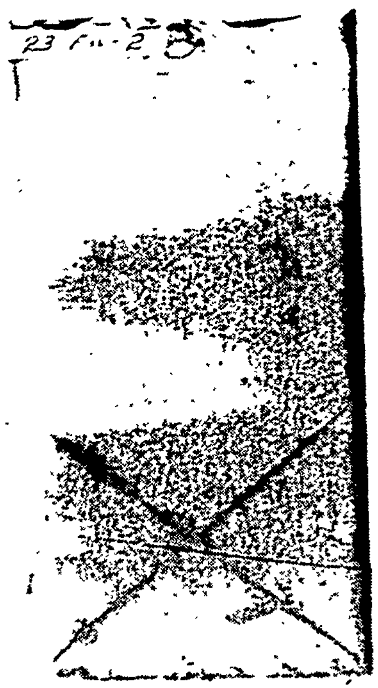
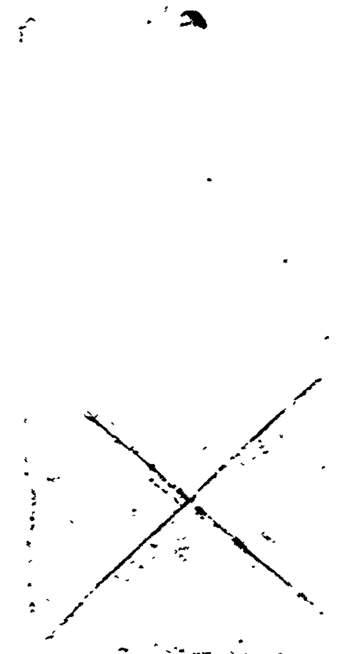


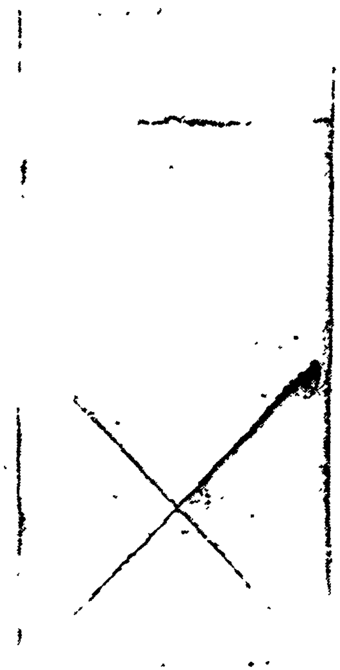
System No. 23 - FWI - Panel No. 2

System No. 24 - FWI - Panel No. 1

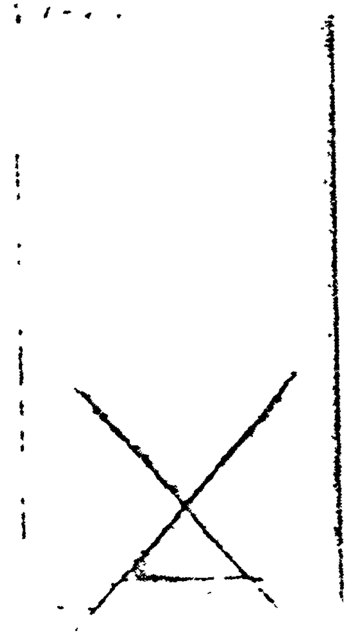


System No 24 - FWI - Panel No. 2

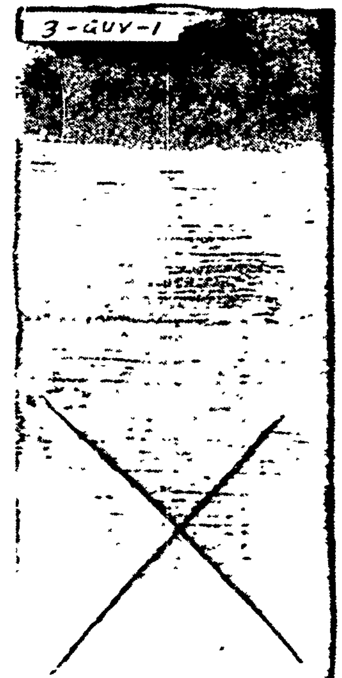
Section 4: QUV Accelerated Weathering Tests



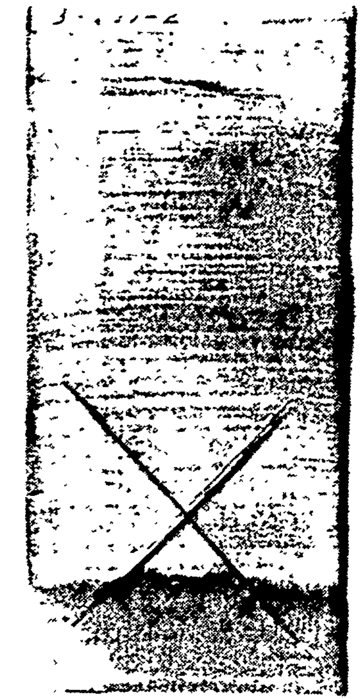
[illegible] No. [illegible] - QUV - Panel No. 1



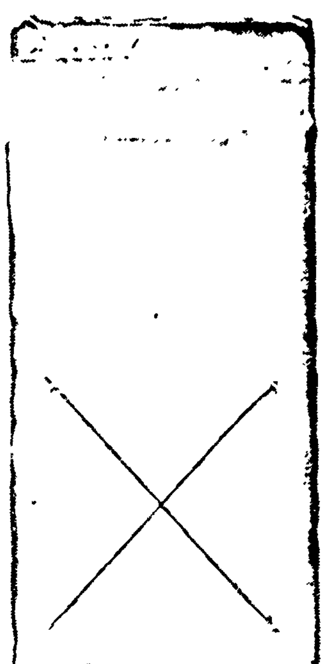
System [illegible] - QUV - Panel No. 2



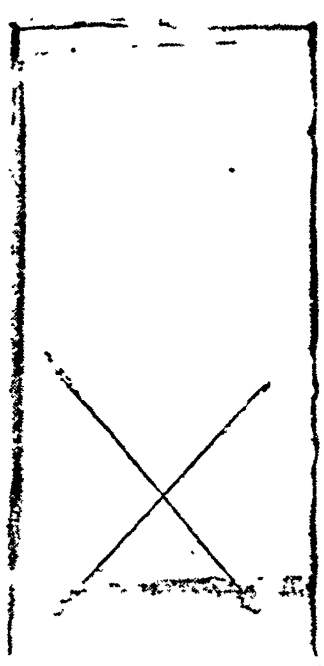
System No. 3 - QUV - Panel No. 1



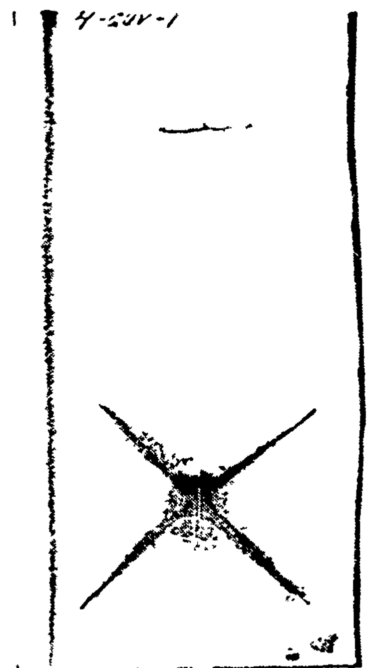
System No. 3 - QUV - Panel No. 2



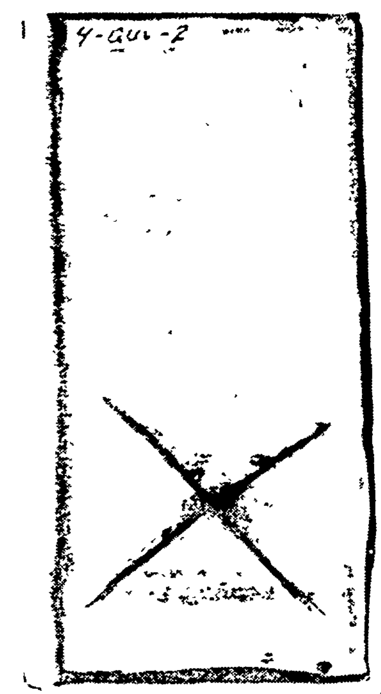
[illegible] - Panel No. 1



[illegible]

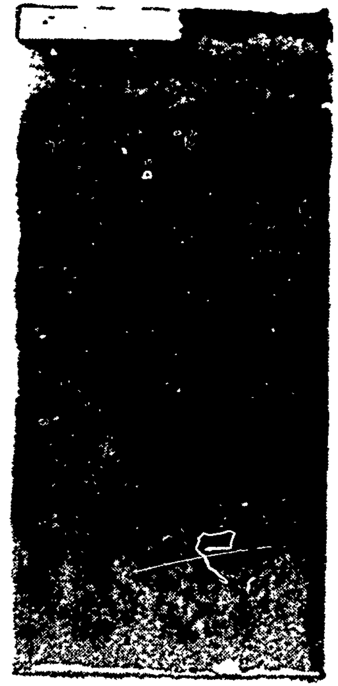


System No. [illegible] - QUV - Panel No. 1



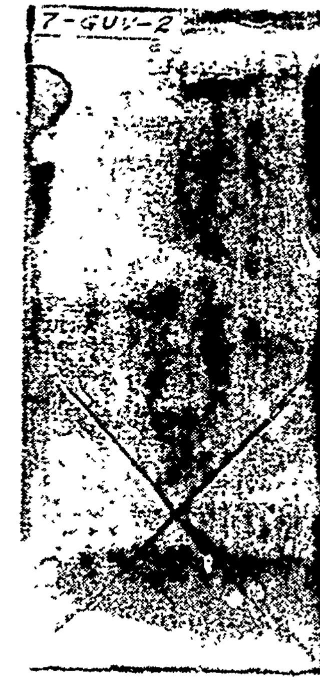
System No. [illegible] - QUV - Panel No. 2

System No. 5 QUV - Panel No. 1

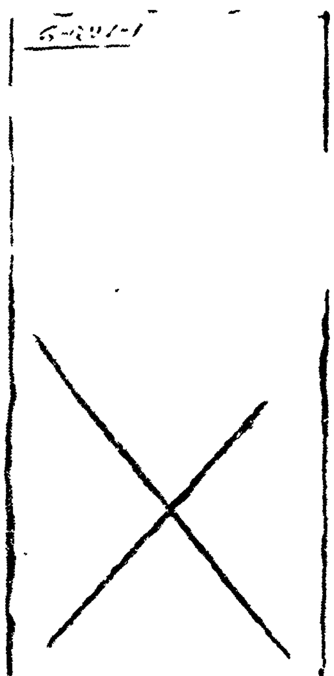


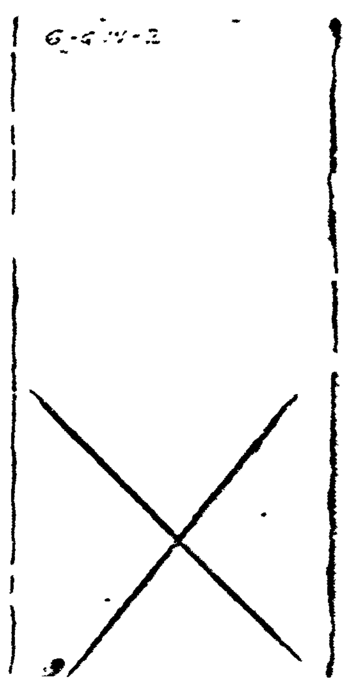
System No. 5 - QUV - Panel No. 2

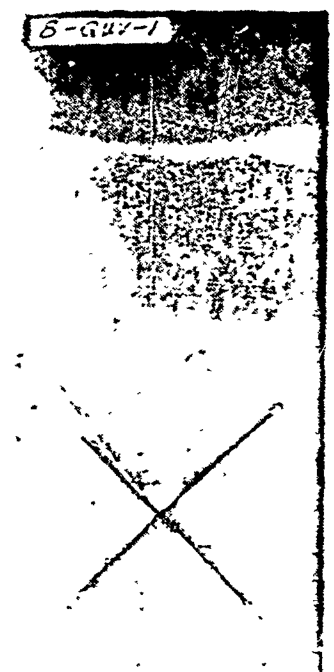
System No. 7 - QUV - Panel No. 1

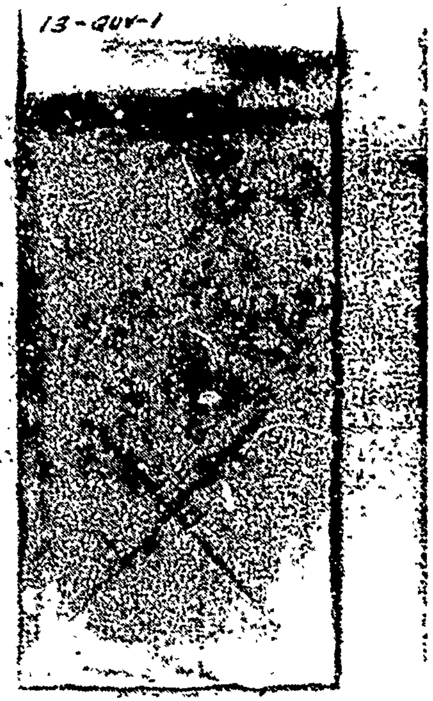


System No. 7 - QUV - Panel No. 2

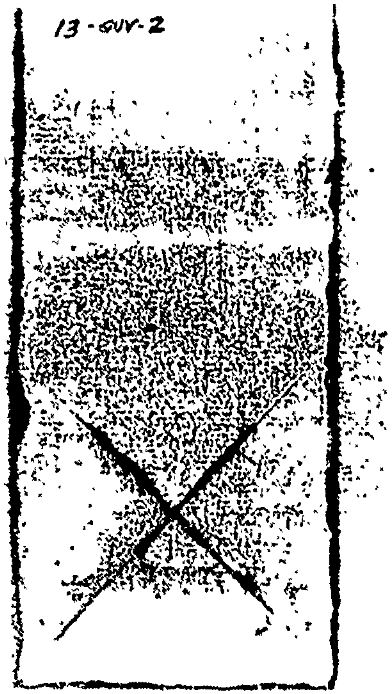








System No. 13 - QUV - Panel No. 1

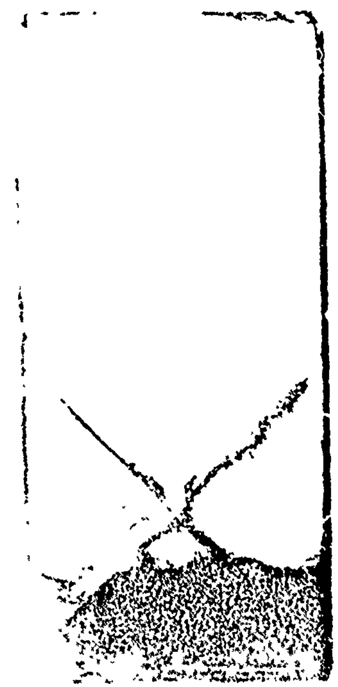


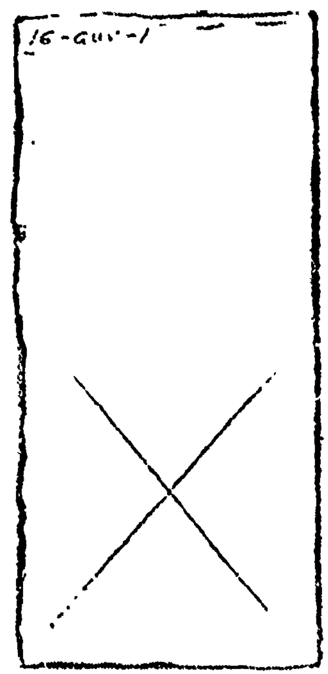
System No. 13 - QUV - Panel No. 2

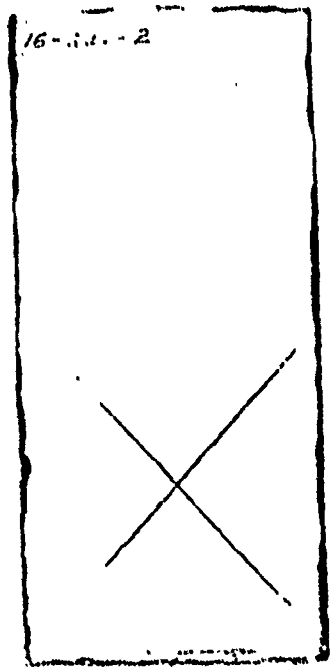

System No. 15 - QUV - Panel No. 1


System No. 15 - QUV - Panel No. 2

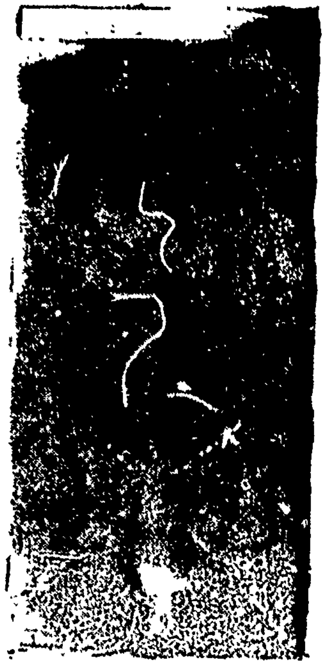

System No. 14 - QUV - Panel No. 1


System No. 14 - QUV - Panel No. 2

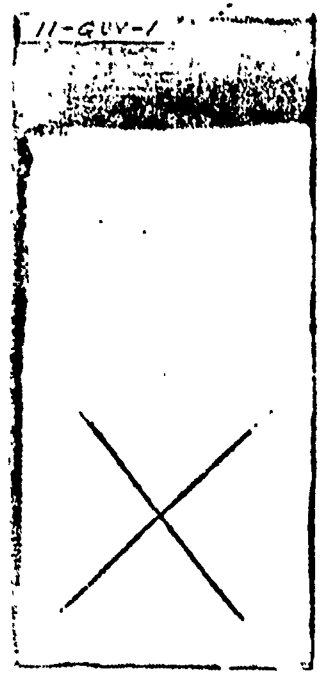

System No. 16 - QUV - Panel No. 1


System No. 16 - QUV - Panel No. 2

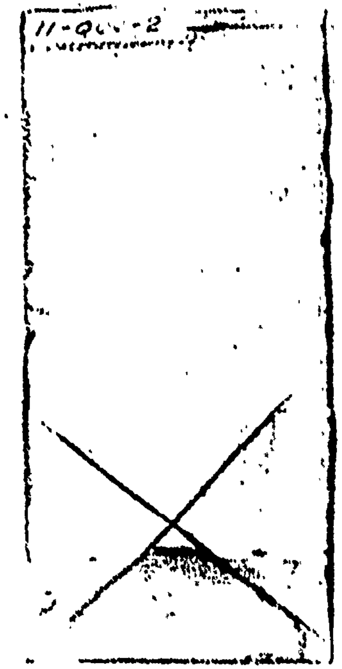
[illegible] No. 3 - [illegible] - Panel No. 1



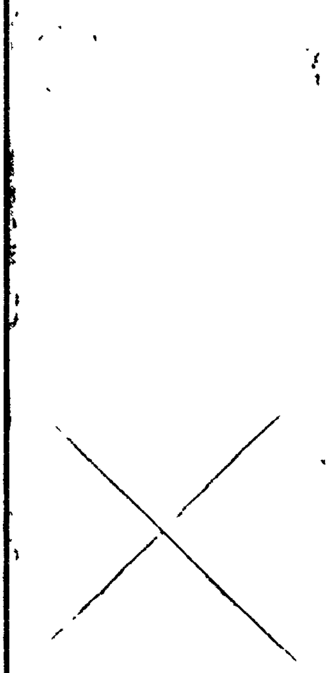
System No. 9 - [illegible] - Panel No. 2

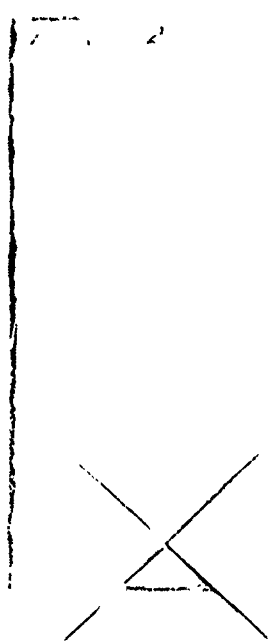


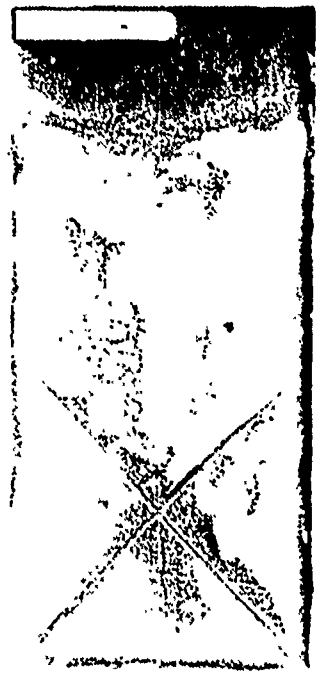
System No. 11 - QUV - Panel No. 1

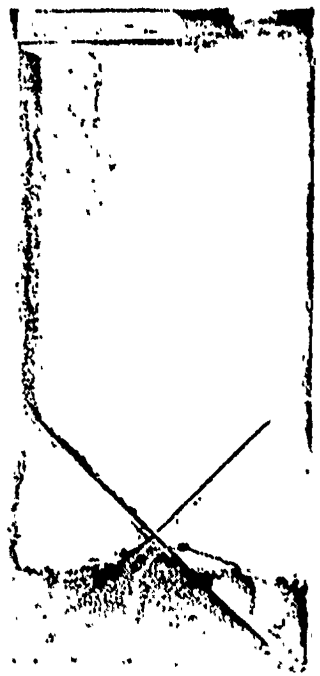


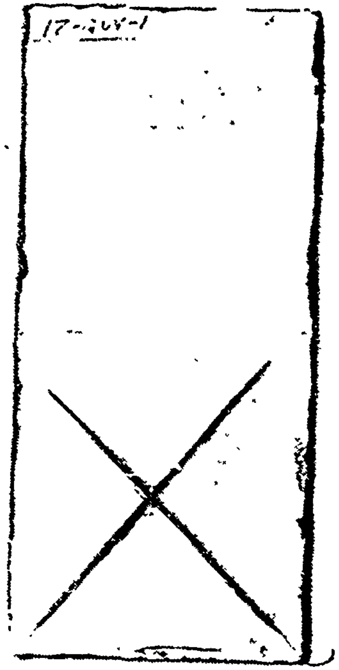
System No. 11 - QUV - Panel No. 2



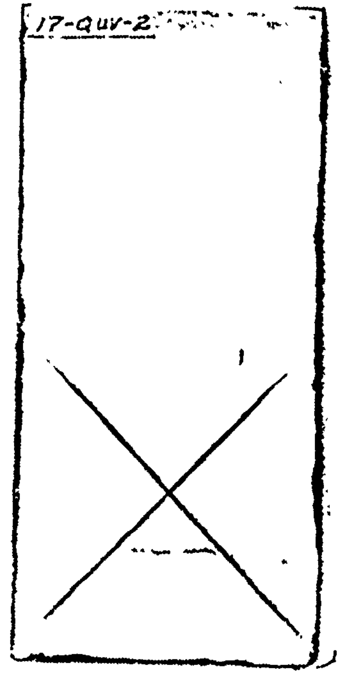




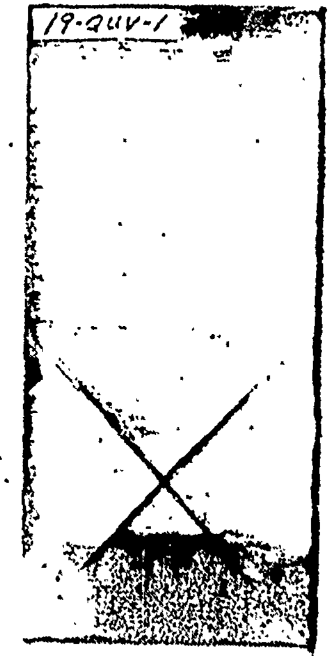




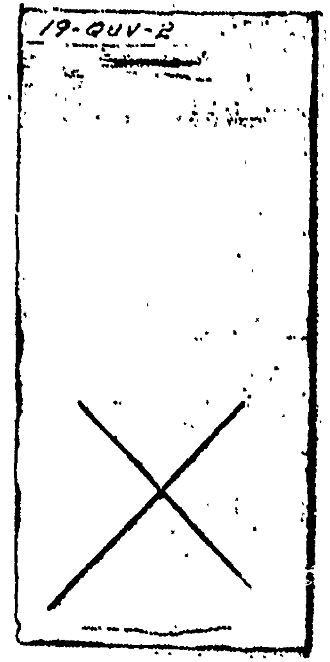
System No. 17 - QUV - Panel No. 1



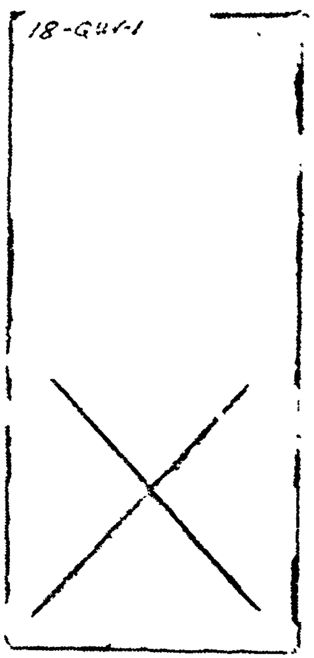
System No. 17 - QUV - Panel No. 2

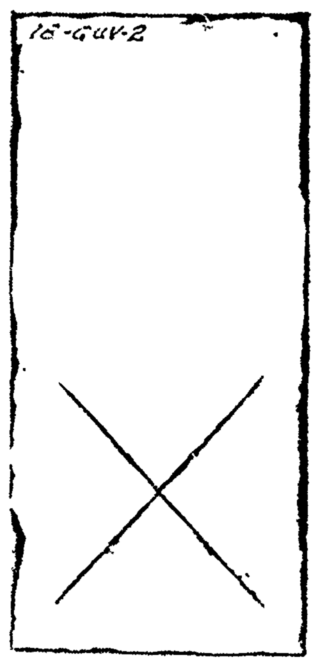


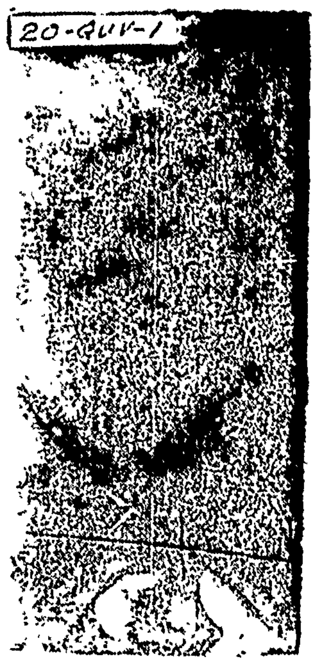
System No. 19 - QUV - Panel No. 1

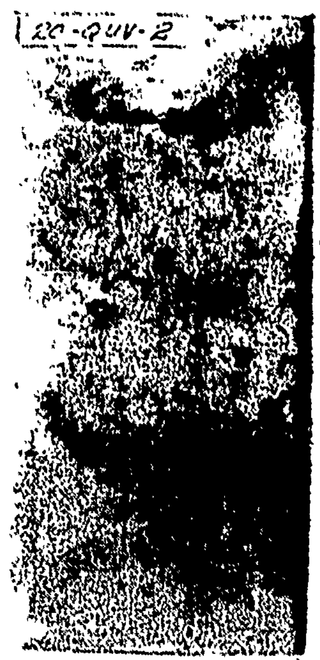


System No. 19 - QUV - Panel No. 2







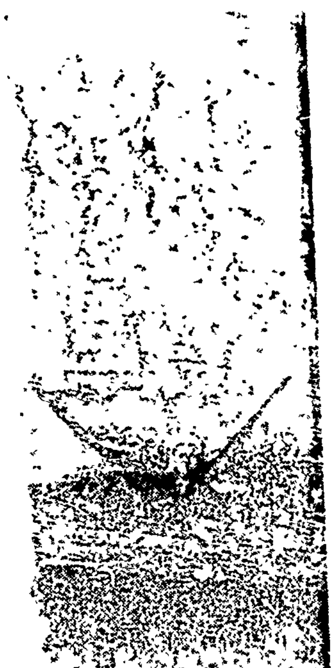


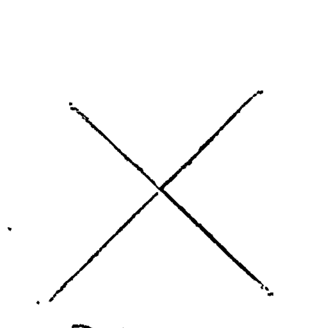
System No. 21 - QUV - Panel No. 1

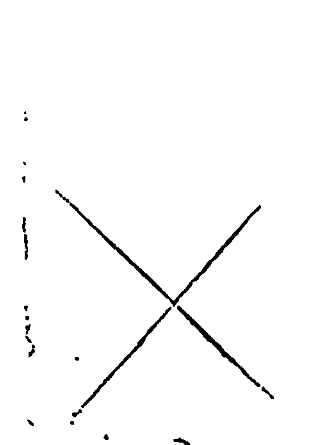
System No. 21 - QUV - Panel No. 2

System No. 23 - QUV - Panel No. 1

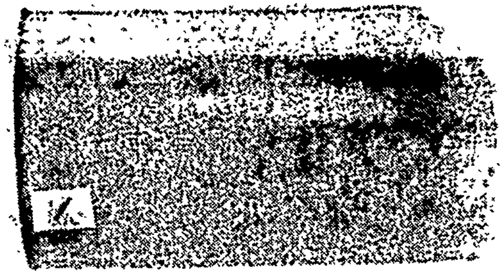
System No. 23 - QUV - Panel No 2



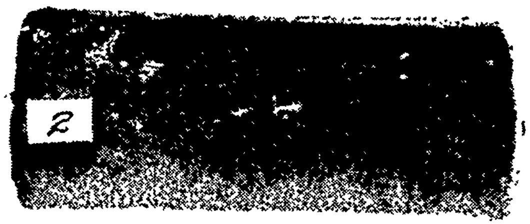




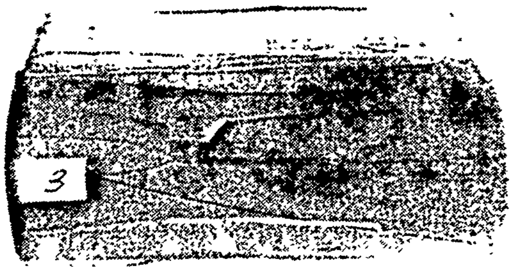
Section 5: Mandrel Bend Tests

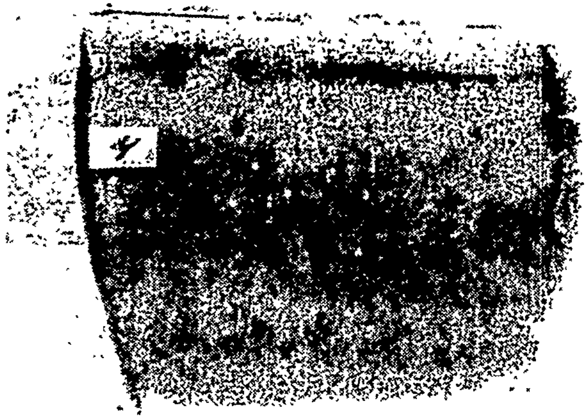


System No. 1

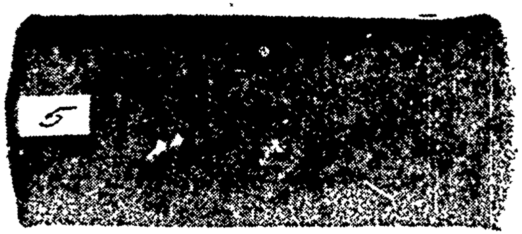


System No. 2

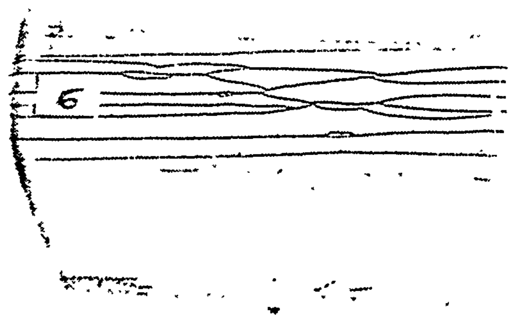


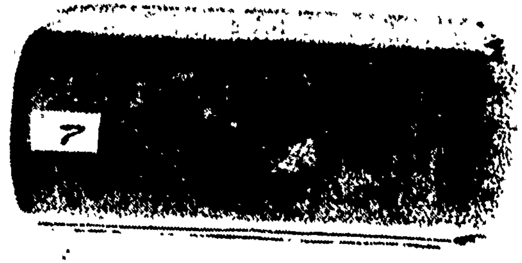


System No. 4



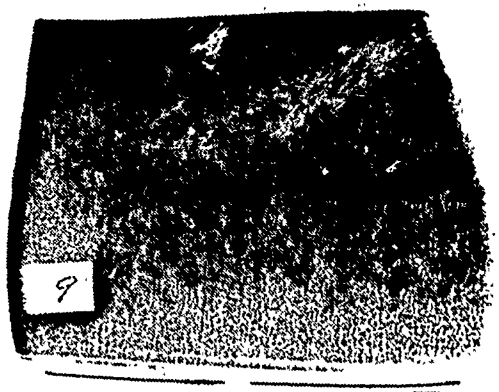
System No. 5

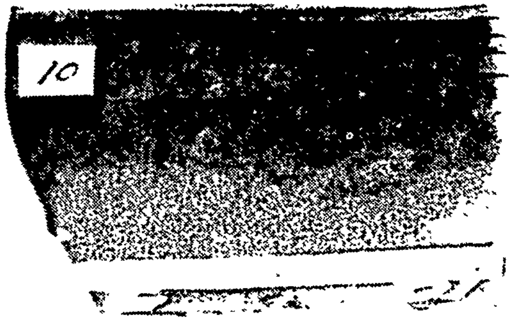




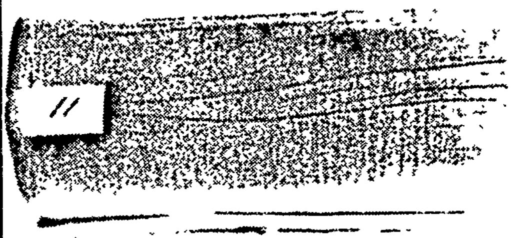
System No. 7

Syst[illegible]

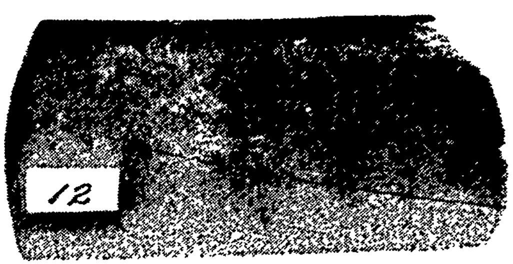


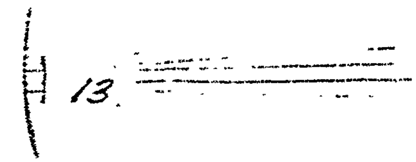


System No. 10



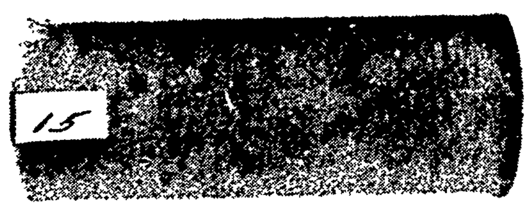
System No. 11



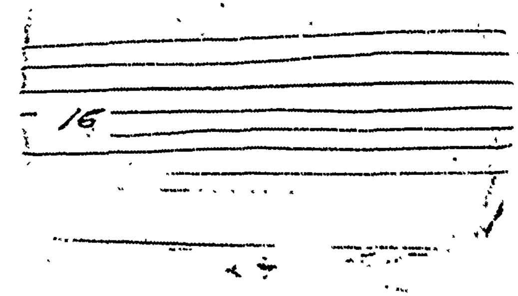


System No. 13

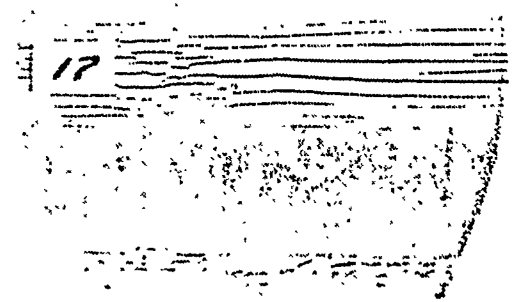
System No. 14



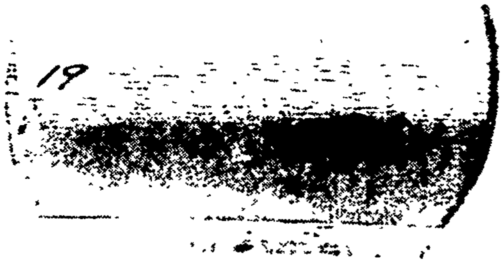
System No. 15



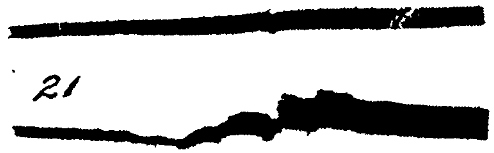
System No. 16

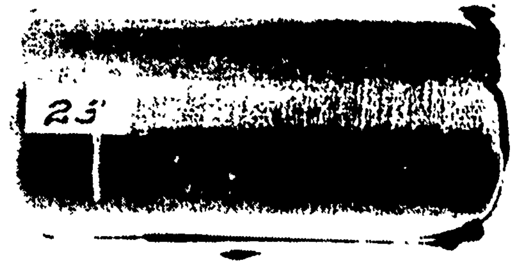


System No. 17



System No. 19





System No. [illegible]